THE USE OF LOW-GRADE AND WASTE FUELS FOR POWER GENERATION

BY

JOHN B. C. KERSHAW, F.I.C.

AUTHOR OF "SMOKE PREVENTION," ETC.

LONDON
CONSTABLE & COMPANY LTD
10 ORANGE STREET WC

PREFACE

THE opening paragraphs of the introductory chapter of this book explain fully its aim and purpose; there is no necessity, therefore, to recapitulate here the reasons that have led the author to prepare at the present time a book upon the use of low-grade and waste fuels for power generation.

It may be stated, however, that the book is based upon articles which have been published during the war period concurrently in *The Engineer* and *The Times* (Engineering Supplement) in this country, and in *Coal Age* and *Chemical and Metallurgical Engineering* in America.

The information contained in the articles has been brought up-to-date, and the form of the articles modified, in order to render them more useful and also more suitable for publication in book form. A few of the excellent Bulletins of the United States Bureau of Mines which deal specially with low-grade and waste fuels have been used extensively in the preparation of the book; and the author's thanks are due to the Acting Director of the Bureau, Mr. H. Foster Bain, for permission to reproduce many of the data and illustrations which have appeared in these useful publications. Nos. 2, 89 and 123 have been specially drawn upon in this respect.

The author's thanks are due also to the editors and publishers of *The Engineer* and of *The Times* (Engineering Supplement) for their permission to make use of the illustrations which appear on pages 78, 119, 174 and 175 of the book; and to Mr. E. W. L. Nicol, of the London Coke Committee, for the information and photographs relating to the use of coke and pitch for steam-raising purposes on pages 62, 63, 65 and 117.

JOHN B. C. KERSHAW.

9, GROSVENOR ROAD,
COLWYN BAY,
November, 1919.

CONTENTS

PART I.—FUELS

CHAPTER PAGE
I. INTRODUCTORY . . . . . . 1—10
II. PEAT . . . . 11—36
III. LIGNITE, BAGASSE AND WOOD WASTE . . 37—57
IV. COKE AND COKE-BREEZE . . . . 58—75
V. CULM AND WASHERY WASTE . . . . 76—94
VI. TOWNS' REFUSE AND GARBAGE . . . 95—111
VII. PITCH . . . . 112—123
VIII. WASTE GASES . . . . . . 124—138

PART II.—SCIENTIFIC CONTROL

IX. FUEL SAMPLING AND TESTING . . . 139—155
X. CALORIMETRIC TESTS . . . . . 156—168
XI. BOILERS AND FURNACES . . 169—184
XII. AUTOMATIC CO_2 APPARATUS . 185—194
INDEXES . . . . . 195—202

LIST OF ILLUSTRATIONS

PART I

FIG. PAGE
1. Pintsch Type of Revolving Eccentric Grate for Gas Producers 3
2. Rehmann Type of Revolving Eccentric Grate for Gas Producers (shallow) 4
3. Rehmann Type of Revolving Eccentric Grate for Gas Producers (deep) 5
4. General Arrangement of Revolving Grate Gas Producers . . . . *Facing* 6
5. Pintsch Type of Revolving Grate Gas Producer (section of) 8
6. Wiesmoor Peat-bog Power System in East Friesland . 16
7. Combined Briquetting and Dredging Machine driven by Electric Power 17
8. Section of Peat Gas-producer Plant at Skabersjo, Sweden 27
9. Plan of enlarged Peat Gas-power Plant at Visby, in Gothland . . . . *Facing* 29
10. Peat Gas Producers at Portadown, Ireland . . . 30
11. German Type of Peat Gas Producer with Ammonia-recovery Plant 31
12. German Type of Furnaces and Boilers for Lignite . . 38
13. German Type of Furnace and Boilers for Lignite (section) 40
14. American Type of Boiler and Furnace for Lignite at Willaston, N.D. (section) . . . . . . *Facing* 44
15. General Arrangement of an English Steam-raising Plant, for burning Wood Refuse . . . . . *Facing* 55
16. Up-draught Type of Gas Producer for Wood Refuse, with Mechanical Tar Extraction (American) . . *Facing* 56
17. Down-draught Type of Gas Producer for Wood Refuse (American) 57
18. Nicol & Schofield's "Sandwich" Feed for Boilers (section). 62
19. Nicol & Schofield's "Sandwich" Feed for Boilers (general view) 63
20. Nicol's Steam-jet Forced Draught Apparatus for burning Coke 65

FIG. PAGE

21. The Tees Gas Producer for Gasifying Coke 75
22. The Bettington Boiler for Coal-dust Firing 78
23. The Hauto Electric Power Station (external view) . . 83
24. Boilers and Furnaces at the Hauto Electric Power Station (section). 84
25. Boilers at the Waste Fuel Power Plant, Cadogan Mine, U.S.A. 86
26. Anthracite Silt or Culm—exact size of - 87
27. Augsburg-Nürnberg Type of Gas Generator . . . 91
28. Kerpely Type of Revolving Grate Gas Producer . . 93
29. Furnace Room of Destructor Plant, New York City (Heenan & Froude) 100
30. Horsfall "Tub-feed" and Charging Gear, at Liverpool . 101
31. Heenan & Froude Trough Grate 102
32. Horsfall Tipping Trough Grate 103
33. Shaft Type of Destructor at Hamburg 104
34. Destructor Plant at Partick (Manlove & Alliott) . . 108
35. Nicol's Special Type of Fire-bar for burning Pitch . . 117
36. Diagram of a Furnace Plant for burning Mixtures of Pitch and Creosote 119
37. Altenheim & Wilson Burner for Producer Gas . . 125
38. Altenheim & Wilson Burner for Blast Furnace Gas . 125
39. The Terbeck Gas Burner 131

PART II

40. Small Grinding Mill for crushing Coal Samples . . 144
41. Sturtevant Grinding Mill for crushing Coal Samples . 144
42. Kenrick Mill for preparing Samples in Laboratory . . 146
43. Sampling Funnel for mixing Fuel Samples . . . 146
44. Darling Type of Calorimeter 158
45. Mahler-Donkin Calorimeter, Bomb Cover and Fuel Holder 159
46. Mahler-Donkin Calorimeter, Bomb and Containing Vessel ready for a test 161
47. Water Jacket and Stirrer for Calorimetic Tests . . 162
48. Efficiency Diagram for a well-managed Boiler Installation 174
49. Efficiency Diagram for a badly-managed Boiler Installation 175
50. Diagram of Heat Units absorbed during Conversion of 1lb. of Ice into Steam 181
51. Efficiency Diagram for a modern Steam-power Plant . 186
52. Portable form of Gas-testing Apparatus 189

INDIAN INSTITUTE OF SCIENCE
LIBRARY
BANGALORE.

THE USE OF LOW GRADE AND WASTE FUEL FOR POWER GENERATION

PART I.—FUELS.

CHAPTER I

INTRODUCTORY

Fuel Conservation by the Use of Low-grade Fuels for Heat and Power Generation

The rising cost of all forms of fuel, due to causes some permanent and some, let us hope, only temporary in character, renders a discussion of the utilisation of cheap or low-grade fuels for power-generation of special interest at the present moment. In past years the British manufacturer and factory owner has been unduly favoured by the cheapness and plentifulness of his fuel supply, and less attention has been given to the problem of the economical use of this raw material of his industrial operations than its importance deserved. The War has changed his attitude towards fuel, however, as it has changed his attitude towards many other problems of his social and industrial life, and there are few manufacturers in this country to-day who are not fully alive to the necessity of conserving our fuel resources, and of making the best possible use of the supplies that are now available for industrial purposes.

The manufacturer, in fact, has been badly hit by the increase in the cost of fuel, and since it is highly probable that a large portion of this increase, though directly due to the War, will prove permanent in character, it is necessary for him to take a wide survey of combustible materials, and to impress into his service all that promise to yield a fair return for the capital and labour involved in their utilisation for heat or power-generating purposes.

Fuel conservation may be effected in two distinct ways. In the first place, there may be a much more widely extended use of low-grade fuels and of other carbonaceous materials and gases now wasted, yet capable of yielding useful heat when burned ; and secondly, there may be a better utilisation of the heat value of the ordinary classes of fuel, this increased efficiency being based upon the application of more scientific methods in the management of the boilers and furnaces in which this fuel is consumed. The great importance of the problem of utilising low-grade fuels is proved by the fact that from 15 to 30 per cent. of the coal which is now being worked in the mines of this country is purposely left underground, either *in situ* in the seam where it occurs, or in the form of coal-dust and slack around the working-face of the seam, because there is no profitable sale for it at the pit head. Nor is the whole of the fuel brought to the surface utilised, for the banks of culm, shale and washery-refuse that can be seen in all coal-mining districts are in most cases rapidly increasing in size. These dumps of pit-refuse, however, like the "tailings" dumps of the South African gold-fields, can still be used at some later date ; but the fuel left underground is lost for ever, since it will never pay to reopen old workings in coal-mines, in order to recover the lower-grade fuel, when the better-grade coal has once been removed from the seam. The loss in this case is therefore a dead loss to the community, and also represents a considerable diminution in the value of our national reserves of fuel—unless means are taken at an early date to check it.

In support of these views concerning the importance of the subject, a few extracts may be quoted from the Report of the British Association Committee, which has been studying recently the question of fuel and its better utilisation for domestic and manufacturing purposes :—

"There can be little doubt but that up to the present we have been wasteful and improvident in regard to our methods of getting and utilising coal, and that not only are great economies in both these directions obtainable, but also that the question of the general adoption of more scientific methods in regard to these matters is one of vital importance, in view of the trying period of economic recuperation which will immediately succeed the War. . . .

"The fact that the available reserves of coal in Great Britain only amount to about one-fortieth, whilst those of the whole Empire do not amount to more than about one-fourth of the world's estimated total, is one which ought to be brought home to every one responsible for the economic development of our national and imperial resources, especially in view of the fact that the United States, whose competition in the immediate future will probably be much more severely felt than ever before, possesses more than half the estimated world's coal, and that also in regard to the two prime considerations of quality and cost of production, she probably compares favourably with Great Britain and the Empire. . . .

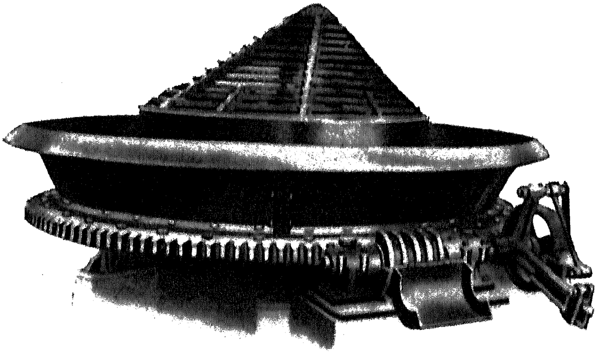


FIG. 1.—Pintsch type of Revolving Eccentric Grate for Gas Producers.

"Part of such wastage, for example, that due to the occurrence of faults in the coal-fields, is unavoidable, but when all such allowance has been made there undoubtedly remains a large wastage in working which might and ought to be avoided. A memorandum is being prepared on the reduction of such wastage by the adoption of 'hydraulic stowing,' a practice which though in vogue on the Continent has not yet been established in Great Britain."—*Report presented at Newcastle Meeting, September*, 1916.

As regards the definition and classification of low-grade fuels, all fuels testing over 25 per cent. of ash and over 10 per cent. of moisture, *i.e.*, containing 35 per cent. or more of incombustible matter, may be classed as "low grade." All coal and coke that passes through a ¼-inch mesh sieve must also be classed as low grade, not on account of its ash contents but on account of its fine state of subdivision.

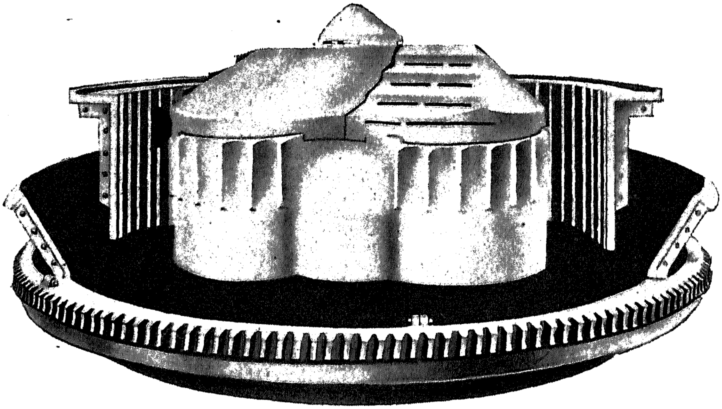


FIG. 2.—Rehmann type of Eccentric Grate for Gas Producers (shallow).

The preliminary and experimental work carried out in recent years in Europe and America has proved that two methods of utilising these fuels are open to the engineer. Either (1) they may be burned alone or mixed with other low-grade fuels of different physical structure ; or (2) they may be gasified in special types of gas producers. If method (1) be adopted some form of artificial draft is required for the proper combustion of the fuel.

Under exceptional circumstances these low-grade fuels may be pulverised and burned in dust-form, but this method can only be used with advantage when the fuel is easily pulverised, or when it contains a large proportion of dust and smalls. Lumps of shale, and of bone-coal, are not easily pulverised, and low-grade fuels containing a large proportion of these ingredients are best burned in lump form upon specially designed grates, provided with the necessary facilities for dealing with the large amounts of clinker and ash produced by the combustion.

As regards *gasification*, several special types of producer have been designed for working with fuels of high-ash contents, and all the difficulties resulting from the large amount and fusibility of the ash have been provided for and overcome. The producers now in use for this purpose are equipped with various forms of revolving ash-pan, by means of which the clinker is crushed and automatically removed. In most cases they are provided also with a water-jacket, to prevent the clinker fusing and sticking to the outer plates of the producer. In the best types of these producers the speed of rotation of the ash-pan and the degree of eccentricity given to the centre-block can be varied to suit the fuel used. See Figs. 1—5, and Fig. 21, p. 75, and Figs. 27, 28, pp. 91 and 93.

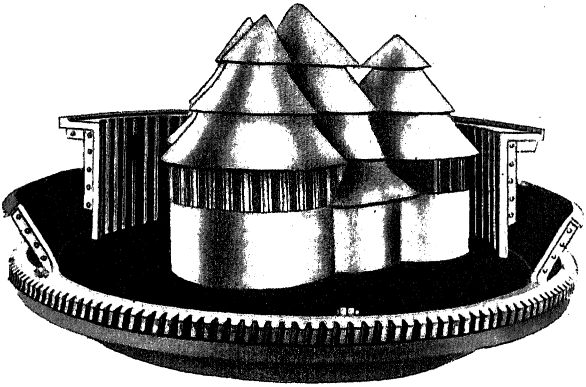


FIG. 3.—Rehmann type of Revolving Eccentric Grate for Gas Producers (deep).

When finely-divided material is used for gasification in these producers, or when a great depth of fuel-bed is necessary in order to obtain a gas of the required composition, it is necessary to increase considerably the pressure of the air-blast. The *Kerpely* high-pressure producer has been designed to meet this particular case. This producer is provided with an enclosed water-seal, and air is introduced above the seal at the same pressure as that introduced below the grate. In this way an automatically-balanced pressure is maintained on both sides of the water-seal, and any pressure of air-blast that is requisite to penetrate the fuel-bed can be employed without risk of blowing the water-seals.

Other types of these eccentric-grate producers for the gasification of low-grade fuels are the *Pintsch*, the *Rehmann* and the *Tees*. Four producers of the latter type have been installed at the new Tottenham Gas Works, in order to generate gas for heating the vertical retorts. Each producer has a capacity of 20 tons coke-breeze per day, and in its main features follows the lines of the *Kerpely* producer—that is to say, it has a rotating-grate, mechanical ash-discharge, and a water-cooled shell. The rotating grate in this case is formed of a heavy cylindrical casting, surmounted by a stepped cone, the whole being mounted eccentrically in the ash-pan. This pan rests on ball-bearings and is rotated by worm-gearing, driven from a shaft running along the side of the producer battery. As the speed of rotation is very slow, only ⅛th to 1¼ revolutions per hour, the power required is almost negligible. The makers of these producers, in fact, estimate this power at ¼ H.P. per producer, but it is usual to install 1–2 H.P. for the work. The hot water from the cooling-jacket may be used for boiler-feed or other purposes, and the heat abstracted from the producer-shell can thus be turned to useful purposes.

Culm, pit refuse and coke-breeze, however, appear at last to be appreciated by the more advanced colliery proprietors and gas-works engineers, and it is doubtful whether the ordinary consumer could purchase on contract at a very low price large quantities of either the one or the other fuel for delivery during the next twelve months. Peat and lignite are not very widely distributed in England. Where then is the British manufacturer to obtain his supplies of low-grade fuels, supposing him to be willing to purchase, say, five to ten thousand tons, for immediate use?

This query brings one to the consideration of the amount of low-grade fuels left in the coal mines of this country, because there exists no demand or profitable market for them at the present time. The proportion of fuel left in the mines, and its quality or physical characteristics, varies in different districts; and that some loss must occur is evident from a study of the methods used for the extraction of seams of coal, often only two feet in thickness, from between the adjacent layers of shale and dirt. The more widely extended use of mechanical coal-cutters in mining work is, however, reducing the unavoidable losses incidental to the winning of the coal, and the instances given below are those of coal left in the mines, not because it is impossible to get it away without collapse of the roof, but because there is no market for it when brought to the surface. The facts are taken from a paper read in 1916 by Professor Henry Louis, of Newcastle, at the Manchester Annual Meeting of the Society of Chemical Industry.[1]

In the South Yorkshire mining district what is known as the Barnsley 9-foot seam is worked by many of the collieries, but only little more than one-half of this is brought up to the pit-head, the top-half of the seam, nearly 4 feet in thickness, being left in the mine because it is a soft coal with easily fused ash, and there is no market for it in the district. Chemically and thermally there is little difference between Barnsley "hards" and Barnsley "softs," but while the former commands a steady sale and a good price, the latter fuel, or 40 per cent. of the whole seam, is absolutely wasted. According to Professor Louis, apart from its softness Barnsley "softs" is a good fuel, and shows only 3·8 per cent. ash, and 13,400 B.Th.U. by the calorimeter.

In the Nottingham and South Wales districts very large amounts of small coal are left in the mines owing to the coal being loaded at the face of the seam with forks having 1½ inch "tines" or prongs, and Professor Louis estimates the loss in these cases at one-fifth of the whole production. In Scotland, in the Lanarkshire and Fifeshire districts, seams known as the "great seam" and the "Ell coal" are only partially worked, the better portions being brought up and the poorer portions left behind. These are typical examples of what is occurring in coal mines all over the country.[1]

---

[1] *Journal Society Chemical Industry*, July, 1916.

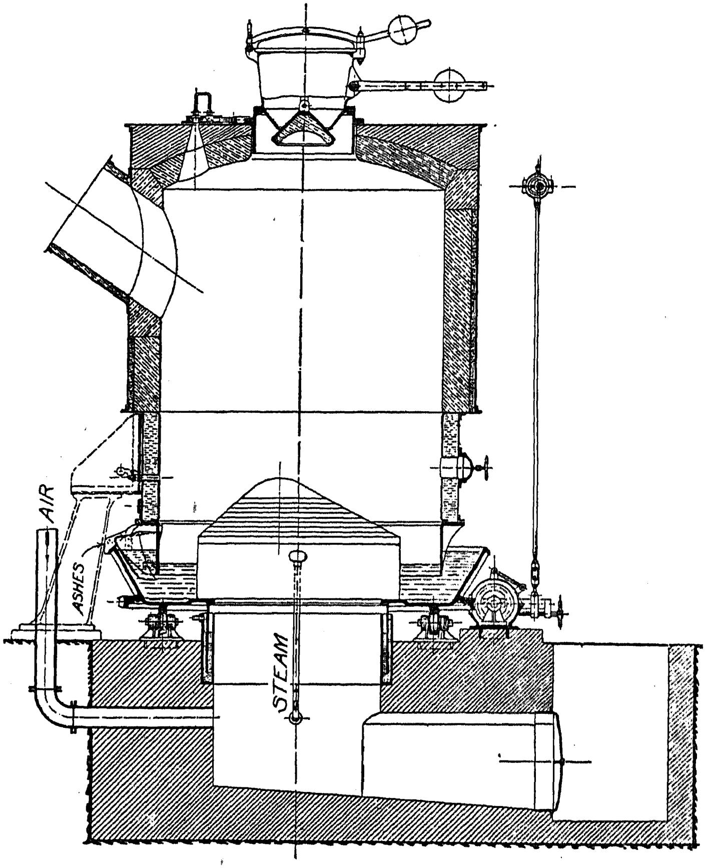


Fig. 5.—Pintsch type of Revolving Grate Gas Producer.

As regards the aggregate amount of this unmined fuel, the annual average output of coal in the United Kingdom

---

[1] See "Final Report of Coal Conservation Committee of the Ministry of Reconstruction," 1918, Cd. 9084, p. 52.

LIBRARY
BANGALORE

during the period 1910—1915 was about 260,000,000 tons, and if we take Professor Louis's estimate of 20 per cent. as within the mark, we here have an annual waste of our fuel resources amounting to 65,000,000 tons.[1] If the colliery owners could be assured of a steady demand and market for this fuel, they would certainly not leave it in the mine, and the remedy for this waste is therefore for consumers of fuel to create the demand by offering to make use of these poorer fuels in their works and factories.

The first step in such a development will be to obtain reliable samples and tests of the fuel; the second to frame a fair contract based upon the results of the laboratory examination, in which allowance will be made for the special difficulties of burning, due to the fine state of subdivision or high percentage of moisture and ash; and the third and final step will be to adapt the methods of burning or gasification to the fuel, so as to obtain the highest possible efficiency from it.

Before passing on to consider in detail in the succeeding chapters of this book the methods that have been employed for using these poorer classes of fuel, it is necessary to point out that in the majority of cases it will not pay to transport them any considerable distance by rail or water, owing to their high percentages of incombustible matter. In order to obtain the greatest possible economy, they should be burned therefore in close proximity to the mining area or pit where they are produced. The only exceptions to this rule are the fuels which are classed as low grade on account of their fine state of subdivision, rather than on account of their high percentages of moisture and ash. In this case the transport charges would be no greater tax upon the heat or power produced than in the case of the ordinary grades of fuel, and the use of coke-breeze and of coal-dust should therefore prove economical even at considerable distances from their point of production.

Finally, one may summarise the whole argument by stating that the methods described deserve the careful attention of all large consumers of fuel in coal-mining areas because the advantages to be gained are twofold, namely, a prolongation of the life of our manufacturing industries, and a reduction in the cost of heat and power to the individual consumer.

---

[1] This 20 per cent. loss is calculated on the gross and not on the net total.

CHAPTER II

PEAT

NEXT to coal, peat is the most widely distributed naturally occurring solid fuel. In fact, if one considers only the area covered by the peat deposits of the world, without relation to their depth or thickness, it is probably true that the deposits of peat now occupy a larger area of the earth's surface than did the lower-lying coal measures, in the early stages of their geological history. The figures given below enable one to form some idea of the enormous extent of the area covered by the peat-bogs in all countries situated in the northern temperate zone. This condition of the occurrence of peat is explained by the fact that the plant growths which produce peat require a moist but cool atmosphere and habitat for their development, and this is never found nearer to the equator than 45 degrees, nor within the arctic circle.

Peat is found in abundance in the following countries : Great Britain and Ireland, Denmark, France, Germany, Hanover, Holland, Hungary, Italy, Oldenburg, Russia, Bavaria, Sweden, and, finally, in the United States.[1] As regards area and extent, the peat-bogs of what were once the Crown Lands of Russia are reported to contain 100,000,000 cubic feet of excellent peat. The Swedish bogs are estimated to represent 3,000 million tons of peat, while the swamp regions of Virginia, U.S.A., cover nearly 1,000 square miles and have an average depth of 15 feet. In Germany, the peat bogs cover 11,580 square miles, and in Ireland, one-tenth of the surface of the whole country. The depth of the Irish bogs varies from 16 to 23 feet, but in certain cases this depth is much exceeded, and some are known to have a depth of 50 feet. Finally, in the United Kingdom, which is so liberally provided with coal-measures, there are, according to Perkin, 6,000,000 acres of peat-bog, with an average depth of 12 feet.

---

[1] See also Bjorling and Gissing, *Engineer*, July 12th, 1907.

All the nations of the world whose industrial activity and prosperity in the past have been based on the development of their deposits of coal are well provided with this alternative source of heat and power.

The question of the best methods of utilising their resources of peat is therefore one of paramount importance for the leading manufacturing countries of the world, for as their reserves of coal become exhausted, and the cost of working them increases, it will be necessary to fall back upon the more recently formed fuel—peat—in order to be able to compete in the world's markets with those countries, such as Sweden, Norway and Switzerland, which possess immense water-powers capable of cheap development for industrial purposes.

This change from coal to peat is already occurring in certain European countries where coal is not plentiful or is of poor quality—and the change will, no doubt, be accelerated by the War, which has doubled the cost of coal-mining, and consequently the price of coal, in nearly all the countries of the world.

Composition and Constitution of Peat.

Peat is a mass of decaying vegetable matter which under suitable natural conditions and with the lapse of time would have been converted into a form of coal. The peat-bogs, to which reference has been made in the introduction to this chapter, may therefore be regarded as partially-formed solid fuels, which, owing to their high percentage of moisture, come under the classification of low-grade fuels. If heat and great pressure were applied to this mass of decaying vegetable matter, and the water were eliminated, a residue would in fact remain which would possess many of the characteristics of coal. This conversion of vegetable remains into peat occurs only in swampy districts, because the water shuts off the decaying plant from any access of oxygen or air, and the decomposition that occurs is due, not to oxidation, but to internal chemical changes which may be represented by the following equation:—

$$6C_6H_{10}O_5 = 7CO_2 + 3CH_4 + 14H_2O + C_{26}H_{20}O_2$$

Cellulose yields carbonic acid gas, marsh gas, water, and peat.

The moisture in peat is therefore largely due to the water which is formed as a result of the chemical changes that accompany its formation; and peat fresh from the bog will often contain from 80 to 90 per cent. of moisture.

By air-drying, with prolonged exposure to wind and sun, this moisture content can be reduced to 20 per cent. Below this limit it is impossible to pass by means of natural agencies, and this fact explains why peat has never come into use for industrial purposes where the supplies of other forms of fuel have been both plentiful and cheap.

The high percentage of volatile matter in peat is another hindrance to its use for industrial purposes, since the heat produced by its combustion can only be economically utilised in special forms of furnace. The low percentage of ash and absence of sulphur, on the other hand, are characteristics of the fuel which count in its favour. The disadvantages arising from the high percentages of moisture and volatile matter, however, have been largely surmounted in the latest methods of using peat for power purposes.

The following are approximate analyses, made in the author's own laboratory, of air-dried English, Scotch and Irish peat:—

	English peat.		Irish peat.		Scotch peat.	
Moisture .	20·3		21·6		26·2	
Coke .	27·9	ash 1·0 fixed carbon 26·9	21·8	ash 2·3 fixed carbon 19·5	24·6	ash 2·1 fixed carbon 22·5
Volatile .	51·8		56·6		49·2	
	100·0		100·0		100·0	

The calorific value of air-dried peat varies considerably, but the average may be fixed at 7,500 B.Th.U., and peat briquettes dried by natural agency may be taken, therefore, as possessing half the value of good coal.

PEAT BRIQUETTES.

The earliest method of peat utilisation was that of slicing the brown and black peat of the bog into small oblong blocks called "turves," and allowing these to dry in the sun and air. The "turves," which in Ireland are cut 24 inches long by 6 or 7 inches square, shrink considerably on drying, and are only about half this size when ready for use. Much of the domestic fuel burnt in the villages and towns of Ireland to-day is peat won from the bogs by hand labour and dried in this way.

Modern methods of briquetting peat, however, are based upon the use of machinery, both for cutting the peat, squeezing out the excessive moisture, and for moulding it into briquettes afterwards—and the aim has always been to reduce the hand labour required for these operations to the lowest possible point.

Some details will now be given of the more notable and successful installations of this kind, commencing with those working abroad, since it is in Germany and Russia that the greatest progress has been made in utilising the peat and bogland resources of the European continent.

Germany.

The manufacture of peat fuel briquettes, before the War, was already a flourishing industry in Germany, and there is no reason to believe that the industry has suffered any set-back during the war period, since the scarcity of coal and rising price in all countries has favoured the production of the cheaper low-grade fuel.

The peat, in the majority of these German installations, is won from the bog by portable centrifugal pump-dredgers, which first cut and pulp the peat by means of rotary cutters, and then transport the pulped mass (which contains fifteen times its own volume of water) to the factory where the briquette-making machinery is installed. Here the pulp is first passed through a centrifugal machine to liberate the greater part of the water, and is then transferred to a cylinder press, which operates on the principle of a paper-making machine and delivers the peat in the form of a thin sheet to the drying cylinders. The moisture, in this way, is reduced to between 15 and 30 per cent., and the peat, in the form of a moist hot powder, is then fed into the briquetting-machine, where it is submitted to a pressure of 30,000 lbs., and is moulded into the form and shape desired for the finished briquette fuel. No binding agent is required since the bituminous matter contained in the raw peat suffices, in the majority of cases, under the combined influence of pressure and heat, to produce a clean and hard briquette, in which the percentage of moisture is between 11 and 15 per cent., and the ash from 9 to 12 per cent. The calorific value of these machine-made briquettes is said to be about seven-eighths that of ordinary coal, and their cost of manufacture in Germany before the War, was from 5*s*. to 7*s*. per ton. A plant to produce 50 tons per day was estimated to cost £16,000.

Peat briquettes are largely used for domestic heating purposes in Germany, since they are practically smokeless. In order to prove, however, that the generation of power is quite practicable with this form of fuel, some details will be given of the very notable Electric Power Generating Station situated on the Wiesmoor Bog in East Friesland, North Germany, which is run entirely with peat won from this extensive tract of bogland. Fig. 6 shows the position of the bog (which is shaded), and the 150-mile district over which the current is distributed. The original power station, marked "A" in the plan, was erected in 1909, and was designed to generate 3,600 H.P. It has been twice enlarged, and now provides considerably over 6,000 H.P. to the docks and harbour at Emden, and to the electric tramways which run into Wilhelmshaven and Oldenburg from the surrounding villages. The Ems-Jade Canal is also operated with electric power derived from the Wiesmoor generating station. The power-house, after the first enlargement, was equipped with four water-tube boilers and superheaters, and with three turbo-generators, each of 1,250 kw. capacity, delivering three-phase current at 6,000 volts. This current is raised, in a separate transformer house, to 20,000 volts, for transmission purposes. Some portion of the electric power is utilised for operating the electric dredging machines, which form one of the chief features of this installation. The dredgers used at Wiesmoor were designed and built by an Oldenburg firm of engineers, and are mounted upon wheels, so that they can be run on wooden sleepers or on rails along the edge of the bog. The dredgers are of the chain-bucket type, the chain being driven by an electric motor placed at the head of the bucket-frame. A second motor, placed to the left, causes the whole bucket-frame to travel in a horizontal direction, backwards and forwards, through a space of 4 metres. The wet turf, containing 90 per cent. of water, is emptied from

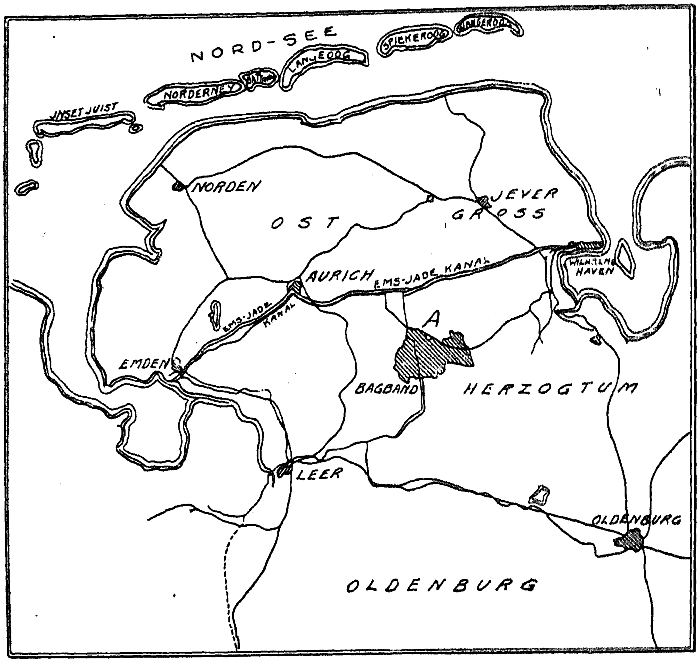


FIG. 6.—The Wiesmoor Peat-bog Power System in East Friesland.

the buckets into a trough and is carried from this by means of a travelling belt conveyor to an electrically operated press. It issues from this press in the form of a uniform thick pulp, and is then, with the aid of another electrically operated conveyor, carried to the cleared and drained portion of the bogland for drying, where it is delivered in the form of a thick felt or carpet.

In addition to the large dredgers, there are many smaller turf-pulping machines at work on the Wiesmoor. These machines are fed by hand, and consist of an electrically operated bucket conveyor and of a pulping and moulding press, which tears apart the peat fibres and then pulps them. The peat pulp issues from the press in the form of a continuous thick belt, and a workman standing by the delivery shoot cuts the peat into strips. These machines are much smaller than the others, and a 12 H.P. electric motor is sufficient for operating them. According to the guarantee of the manufacturing firm, one machine in a ten-hour day can produce 60,000 to 80,000 turf sods or briquettes. Fig. 7 shows one of these electrically-operated combined briquetting and dredging machines.

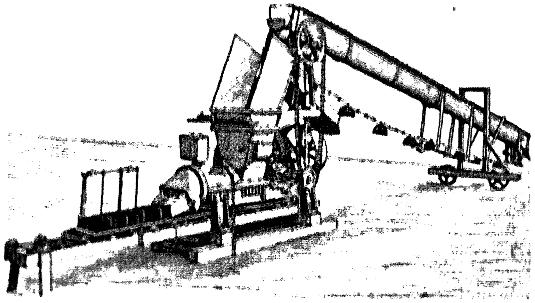


FIG. 7. Combined Briquetting and Dredging Machine.

The size of the blocks of half-dried peat, when first cut into blocks, is 4 inches by 5 inches by 13 inches. As soon as a dry crust has formed upon them so that they can be handled they are stacked in small heaps, where they are left exposed to the sun and air until the moisture contents have been reduced to 25 or 30 per cent., and the blocks have shrunk in size to 2 inches by 2 inches by 10 inches. They are then loaded in cars, which are dragged along a small-gauge railway by a benzol motor to the power-house. In the summer months of the year the output of dried peat by the dredgers and drying grounds exceeds that of the requirements of the generating station, and the surplus dried peat is therefore built up in large stacks in the open, or is stored in covered sheds. When once dried and hard the peat blocks do not readily take up fresh water.

The combined dredging and briquette-moulding plant installed on the Wiesmoor can produce in the usual five summer months' campaign (from April to August) 30,000 to 35,000 tons of dried turf briquettes. Progress is chiefly directed towards reducing the cost, by dispensing more and more with hand-labour, both in the winning of the turf and in the after process of drying and storing it until used.

As regards the methods adopted for burning the fuel after drying, as described above, a series of travelling belt-conveyors carry the peat briquettes to the storage bunkers, and then, after screening and weighing, to the feed-hoppers attached to each boiler. The grates are inclined at an angle of 36 degrees to the horizontal, and are divided into two portions, each of 43 square feet superficial area. The halves are fed alternately with briquettes by raising a lever, which actuates a hinged door on the fire-side of the feed-hopper. Since the calorific value of the air-dried peat fuel is low, averaging only 5,400 B.Th.U., the supply of fresh fuel must be frequently made, and careful regulation of the air-supply is necessary in order to avoid great excess of air, and a low evaporative efficiency in the boilers.

A steam-raising test made soon after the Wiesmoor plant was started gave an evaporation of 3·01 lbs. water per lb. of dried peat and a boiler efficiency of 73·5 per cent. The mean calorific value of this peat was 4,824 B.Th.U., or just one-third that of good coal. Working out the cost of the fuel from these figures, taking the price of the turf briquettes at 5s. per ton, and the fuel consumption at 2·5 kgs. peat per kw.-hour, we find that the fuel required to generate 1 kw.-hour will cost between ·144 and ·168 of a penny. This compares quite favourably with the cost of coal in the best managed large modern power stations.

Russia.

Before the War Russia was second only to Germany in the number and capacity of its installations for producing peat fuel. According to Haanel, the number of separate plants in 1910 was 1,300, and the output of machine peat amounted to over five and a half million tons annually. Many private plants existed in connection with cotton-mills and other manufactures, some of which were producing nearly a quarter of a million tons of peat fuel per annum. The method used in these Russian machine-peat plants was very similar to that described above as in operation on the Wiesmoor bog in East Friesland, that is, the peat was cut and pulped by a combined type of machine, it was then formed into blocks by hand labour and was finally dried by exposure to the sun and wind in the open air.

Canada.

The Canadian Government in 1909–10 erected a small experimental plant for producing machine-made peat at Alfred, in Ontario, in order to encourage the development of the peat resources of the Dominion upon sound lines. This plant was very similar in design and principle to those already described as at work in Germany and Russia, the only improvement being that a system of cables was employed to transport the pulped peat to the drying grounds. The peat produced at this plant in the 1911 drying season had a moisture content of 16 to 20 per cent., and was employed for a series of steam-raising tests in two different types of boiler: a Babcock & Wilcox Marine type of water-tube boiler, and an internally-fired boiler of the locomotive type. Bull. 17 of the Canadian Department of Mines contains a full record of these tests, and the table given below gives a summary of the figures obtained in the six main tests :—

	Water-tube Boiler.			Fire-tube Boiler.		
	1	2	3	4	5	6
Net calorific value of the fuel as fired, B.Th.U. per lb. . . .	7,490	7,490	6,990	7,130	6,970	7,110
Peat fired per hour, lbs.	476	586	569	160	214	341
Peat fired per square foot of grate surface, per hour, lbs. . .	20·5	15·5	15·0	17·7	23·8	37·9
Equivalent evaporation per hour from and at 212° F., lbs. . .	1,950	2,322	2,250	621	802	1054
Equivalent evaporation per hour per square foot of heating surface, lbs.	2·88	3·43	3·32	2·89	3·73	4·9
Lbs. of dry flue gas, per lb. of peat . .	12·4	9·8	11·1	9·8	9·1	6·5
Temperature in flue leaving boiler, deg. F.	720	760	715	690	690	750
Equivalent evaporation from and at 212° F. per lb. of peat fired, lbs..	4·10	3·96	3·95	3·89	3·74	3·09
Thermal efficiency of boiler furnace and grate, based on the net calorific value, per cent.	53·1	51·3	54·8	52·9	52·1	42·2

These efficiencies are low when compared with those said to have been obtained at the Wiesmoor Power Station, but it must be remembered that peat contains a very high percentage of hydrogen, and that when heated, two-thirds of the combustible matter it contains is liberated in the form of hydrocarbon gases. A very large combustion-chamber is therefore required, with secondary air-admission, to obtain good results with peat fuel, and this does not appear to have been arranged for in the Canadian tests. The high percentages of moisture and hydrogen also lead to a further loss of heat in the waste gases, a loss which is unavoidable unless they are cooled below 212° F. in the economisers—for this moisture evaporates, the hydrogen on combustion forms aqueous vapour or steam, and the latent heat of this steam, which is mingled with the other products of combustion, is generally lost. Since peat fuel contains, as a rule, a much lower percentage of sulphur than coal, the best method of obviating this difficulty would be to have a specially large economiser to each boiler or set of boilers, and to reduce the temperature of the hot gases to 150° F. before allowing them to escape up the chimney. By this plan, using water-tube boilers with specially designed large combustion chambers, the efficiency obtained with peat fuel for steam-raising purposes could no doubt be raised to between 60 and 70 per cent., when calculated out on the dry fuel.

CARBONISING.

Many processes have been devised for carbonising peat in closed retorts or ovens, the aim being to obtain a more condensed and marketable form of fuel than is obtained by briquetting or machine treatment of the raw peat. In these processes the air-dried machine-treated peat, obtained as already described under section 2, is employed as the raw material of a further process of enrichment, artificial heat being employed to drive off the remaining moisture and some of the hydrocarbon gases. None of these processes has yet obtained general application, for the simple reason that in the majority of cases the increase in the calorific value of the chief product, peat-coke, and the value of the recovered by-products, is not sufficient to cover the costs of the additional treatment. Under special conditions as regards the market for peat-coke, and for the creosote, light oils, acetate of lime and other by-products, the peat carbonising processes can be worked successfully, however, and both in Norway and Germany there are installations of this type in actual operation. The processes are distinguished as "dry" or "wet" carbonisation processes, according as to whether dry heat or superheated steam is employed to act as heat carrier to the peat contained in the retorts.

"DRY" CARBONISATION PROCESSES.

The *Jebsen* process of dry carbonisation is based upon the application of electrically produced heat, and was first worked upon an industrial scale in the years 1901–1902 near Bergen, in Norway. So far as the writer is aware it is still operated at this place—but it does not appear to have made headway in any other locality. The peat, dried as far as possible by the sun and air, is moulded into suitably shaped blocks and is placed in retorts, the walls of which are covered with asbestos, or other non-conducting material, unacted upon by the gases which are produced when the peat is heated. The charge of peat is then raised to 450° C. by means of electric resistance coils placed *inside* the retort in contact with the raw peat, so that the heat produced in them is transmitted directly to the charge without any losses by conversion or radiation. By this means, some of the difficulties of heating the charge of peat are overcome, but the method is applicable only where electric power is generated at an exceptionally low cost, as in Norway. The gas produced from the peat is used to dry the blocks before they are placed in the retort, in a long heating chamber worked upon the counter-current principle—and the tar obtained is worked up for the usual by-products of the peat-coking process.

THE *ZIEGLER* PROCESS.

This method of carbonising peat in closed retorts was brought out by Dr. M. Ziegler in 1892, and it has been worked successfully since that year at several localities in Germany and Russia. The peat, in this case, is carbonised by the application of artificial heat obtained by burning the gas given off from the retorts. Where the process is most successfully worked, the surplus gas suffices to generate power for operating the dredging and pulping machines by aid of which the peat is won from the bog — and the waste heat of the gas which passes away from the retorts is also utilised to dry the peat blocks before carbonising.

As regards the output of solid fuel by the dry coking process, about one-third of the weight of the raw peat charged into the retorts is obtained as a "peat-coke," specially suitable for smiths' use and metallurgical work, on account of its low contents of sulphur and ash. According to an estimate made by Dr. Ziegler, the yield of by-products from a plant coking 100 tons of air-dried machine peat per twenty-four hours will be as follows :—*Creosote oil,* 3,100 lbs. ; *Acetate of lime,* 1,320 lbs. ; *Sulphate of ammonia,* 900 lbs. ; *Paraffin wax,* 715 lbs. ; *Pitch,* 440 lbs. ; *Light oils,* 280 gallons ; *Heavy oils,* 95 gallons ; *Methyl alcohol,* 65 gallons. This estimate, however, is only correct for the peat found in the locality where the plant which gave this yield is situated, and it is important to note that the financial success of the *Ziegler* process is very dependent upon the character and the purity of the peat charged into the retorts. The existence of good markets near at hand for the peat-coke and by-products of the process is also a *sine qua non* of its successful operation. The *Ziegler* plants erected in Europe were at Oldenburg and Beuerberg, in Germany, and at Redkino, in Russia ; but the last-named is reported to have not achieved a permanent success, owing to lack of demand for the by-products.

That the Germans are still devoting attention to the dry distillation of peat is shown by the fact that so recently as 1916 a patent was granted to Limbers (No. 302322.—November 3rd, 1916) for an improved form of retort, in which the heating is to be effected in three stages by aid of heated non-oxidising gases which pass over and through the mass of fuel.

WET CARBONISING PROCESS.

The wet carbonising processes depend upon the use of superheated water or steam, and considerable pressure for raising the temperature of the peat to 300° or 400° F. In the author's opinion it is doubtful if any real carbonisation occurs at this temperature, and it is much more probable that the hardening effect of the treatment upon the peat is due to the breaking down of some portions of the cell structure, and to the fact that more of the water and moisture can be expelled afterwards by mechanical pressure than is the case with ordinary machine peat.

The most noteworthy of these processes of peat carbonisation was the *Ekenberg* process which was brought out in 1904, and was tried upon a working industrial scale in Sweden. The wet carbonising furnaces used in the trials consisted of a series of iron pipes, some 36 feet long, through which the wet peat, in the form of finely divided pulp, was forced at a pressure of 150 lbs. to the square inch. Each tube was double, and the peat pulp, after passing down the larger outer tube, returned along the inner smaller tube, and thus gave up some of its heat to the incoming pulp. The outer tubes projected for half of their length into the fire-box of the furnace, and were heated here to the required temperature by coal or gas. *Ekenberg* claimed that this heating under pressure destroyed the cells of the slimy hydrocellulose compounds, which enclosed a large proportion of the water contained in the peat, and that, after submitting the peat to his process, the greater portion of the water could be expelled by mechanical pressure alone. The water-free wet carbonised peat tested 11,000 B.Th.U. per lb., and the cost of production was estimated to be from 6*s*. 8*d*. to 8*s*. 9*d*. per ton, according as to whether machine or hand-labour was employed for winning the peat from the bog. Although the *Ekenberg* process received an extended trial in Sweden, and was much discussed by engineers, having been the subject of a paper read by the inventor before the Iron and Steel Institute, in 1909, the writer believes that it is not now in operation, the costs of operation having proved excessive. A modification of the process has, however, been introduced into France, and has been operated successfully in the development of the peat deposits at Ille-et-Vilaine. The following description of the process is taken from an article by Messrs. Galaine, Lenormand and Houlbert, which appeared in *Comptes-Rendus* of September 3rd, 1917 :—

The peat is first treated in presses of the Mabille or Aurep type, which give a pressure of 710 to 1,420 lbs. per square inch, and easily reduce the original water contents of from 80 or 90, to 60 per cent. The partially dried peat-blocks, or "turves," are then placed in a suitable carrier, and are introduced into horizontal autoclaves, where they are heated by steam to 160° C. for a period of twenty-five minutes. On removal from the autoclaves, the hot briquettes may be a second time passed through the press, but this is not essential. They dry quickly in air down to 20 to 25 per cent. water, but it is better to place them in a heated chamber for the final stage of the process. The final product is quite different in physical and chemical properties from briquettes of ordinary peat, and the authors have given it the name of "tourbon." They regard it as a half-formed coke, and state that its heat value is about 6,500 kg. cals., or 10 per cent. higher than that of dried peat. As the hydro-cellulose compounds have been destroyed by the temperature attained in the autoclave the product does not absorb more moisture after it is once dried. An approximate analysis of the anhydrous "tourbon" obtained from the peat deposits of Chateauneuf, at Ille-et-Vilaine, gave the following figures :—*Volatile matter*, 61·3 per cent.; *fixed carbon*, 36·6 per cent.; *ash*, 3·1 per cent. By arranging the autoclaves in batteries with suitable arrangements for making use of the heat of the exhaust steam it is possible to carry out the process with an extremely high efficiency as regards utilisation of the heat, the figures varying from 85 per cent. to 91 per cent.

GASIFYING THE PEAT IN GAS-PRODUCERS.

Gas-producers have been designed in recent years that can be operated quite successfully with solid fuels containing up to 35 per cent. water, and this fact has led engineers to devote considerable attention to the possibilities of utilising peat for gas-producer work. The fact that the low temperature obtaining in the producers favours the production and recovery of ammonia is another point in favour of the complete gasification of the peat, since the average nitrogen contents of many peat-bogs is higher than that of the ordinary coal measures. Many forms of special producer and plant for the gasification of peat and recovery of the ammonia have been patented and tried upon an industrial scale in Europe during the past decade—and before the War there were quite a large number of these peat-gas power plants in successful operation in Germany, Sweden, Russia, Austria, Italy and Ireland. The type of gas-producer that has proved most satisfactory with peat is that known as the double-combustion zone producer, the gaseous products that collect above the charge of fuel being drawn or forced downwards through the incandescent carbonaceous matter, in order to decompose the larger portion of the tarry vapour contained in these gases, before they are used in the engine. Practical tests have proved that more power is obtained by this simple gasification process than when by-product recovery is carried out. The decision as to whether there will be any economic gain by separating the tar and recovering the ammonia must depend upon local conditions, the amount of nitrogen contained in the raw peat, and the size of the plant.

Under the best conditions one ton of peat gasified in a double-zone suction gas-producer, and utilised for driving a modern gas engine, will yield the same amount of power at the engine-shaft as one ton of good coal employed for steam-raising and power generation, in an up-to-date steam-driven power plant. In support of this statement the following figures are given, taken from an actual test carried out in Germany in 1911, with a 300 H.P. suction gas-producer and engine, using as fuel a peat testing 23·4 per cent. moisture, 4·2 per cent. ash, and 7,108 B.Th.U.

The consumption of peat during the tests was 2,074 kgs. at full-load, and 1,736 kgs. at half-load—the consumption per E.H.P. hour being ·99 kg. and 1·45 kgs. respectively. The gas obtained from the producer at full-load tested as follows :—H, 17·15 per cent. ; CO, 15·85 per cent. ; O, 1·02 per cent. ; CO_2, 12·34 per cent. ; N, 52·2 per cent. ; and the

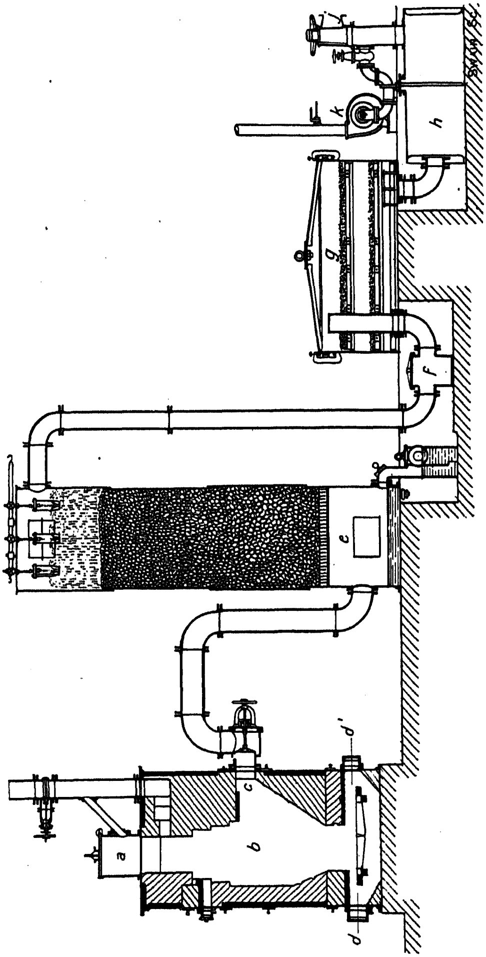


FIG. 8.—Section of Peat Gas Producer Plant at Skabersjo, Sweden.

calorific value of the same was 120·2 B.Th.U. per cubic foot. Assuming the air-dried peat could be delivered into the producer from the bog at a cost of 4*s.* per ton, the cost of fuel per kw.-hour in this plant was only ·077*d.*, which is a far lower figure than could be obtained with any other fuel.

Some typical installations of peat-gas power plants will now be described :—

Sweden.

One of the earliest installations of this type to be erected was that at Skabersjo, in Sweden. This plant was started in 1904 and enlarged in 1906—and, so far as the writer is aware, it is still in operation. A large peat bog exists in this locality, at a distance of only three miles from the town, which is supplied with electricity for heat and power purposes from the generating station at the bog. Fig. 8 is a sectional elevation of the producer, scrubber and fan. The original installation was designed to produce 150 H.P., and this being quite successful, the plant was duplicated in 1906 and increased to 300 H.P. capacity. Only 750 tons of air-dried peat are required per annum to give this power, and there is consequently little difficulty in obtaining the peat from the bog with the aid of the local farmers during the working season, which, in this locality, lasts from April 15th to September 1st. The power for working the dredger and pulping machine is obtained from a 35 H.P. motor, supplied with electric current from the central generating station. Two Koerting suction-gas producers specially designed for peat gasification are installed at this station, with two 150 H.P. Koerting gas engines of the twin horizontal single-acting type. These engines are direct coupled to three-phase alternators which generate current at 3,000 volts for transmission to the town of Skabersjo, where it is sold to consumers for lighting purposes at 4½*d.* per unit. The air-dried peat was delivered before the War at the producers at a cost of only 3*s.* 4*d.* per ton—whereas bituminous fuel at this place costs 16*s.* per ton.

Another successful and larger peat power-gas installation,

INDIAN INSTITUTE OF SCIENCE LIBRARY BANGALORE

equipped with Koerting producers and engines, is in operation at the cement works situated at Visby, in Gothland. The original plant here was erected in 1908, and consisted of one 250 H.P. producer and gas engine, of the horizontal single-acting type; but in 1911, when Fernald[1] visited the plant, the equipment was being increased to 1,500 H.P. Fig. 9 shows the plan of the enlarged power station. The peat-working season on the bog at Visby extends from April 15th to August 8th, and all the peat required for the winter use should be dry and in the storage bins by October 1st in each year. The peat machine originally used in 1908 required 42 H.P., and when worked with a squad of ten men it produced 60 tons of "dry" peat per day of ten hours. The term "dry" applied to this peat was somewhat misleading, as it still contained 25 or more per cent. water, according to the weather conditions that prevailed when it was harvested. With this machine the peat was excavated by a bucket-dredger and conveyor, was passed through shredding and mixing devices, and was then delivered into the cars in a pasty mass. It was transported in this state to the drying fields, was dumped into a frame on the ground, and finally was rolled and divided into bricks by means of blades on the roller, and a 3-inch disc cutter operated by another workman. This "dry" peat contained 25 per cent. to 40 per cent. moisture, the bricks measured 8 to 10 inches in length, 4 inches in width, 2 inches in thickness, and weighed $1\frac{3}{4}$ lbs. The cost of this peat, when collected at the bog ready for delivery in cars to the gas-producers, was 5*s*. 8*d*. per ton.

Ireland.

The most successful example of an industrial power-plant operated with peat in Ireland is that of Messrs. Hamilton, Robb & Co., at Portadown, Co. Armagh. This plant has a capacity of 400 H.P., and has been in continuous operation since 1911. The equipment consists of two Crossley gas-

---

[1] "Producer Gas-power Plants—Developments in Europe," U.S.A. Bureau of Mines, Bull. 4, 1911.

1328 662·6 N201

producers, specially designed for the gasification of wet peat, and two Crossley gas engines of 120 and 150 H.P. respectively. The peat is obtained from a bog 12 miles distant from Portadown, and after air-drying, is transported to the works by water-carriage. The gas-producers are worked on the suction principle, and no attempt is made to recover any by-products, although scrubbers are employed to remove the tar that has escaped destruction in the producers (see Fig. 10). The composition of the gas is as follows :—H, 18 per cent. ; CO, 19 per cent. ; CH_4, 1·6 per cent. ; CO_2, 7 per cent. ; N, 54 per cent. ; and the calorific value of the gas is 140

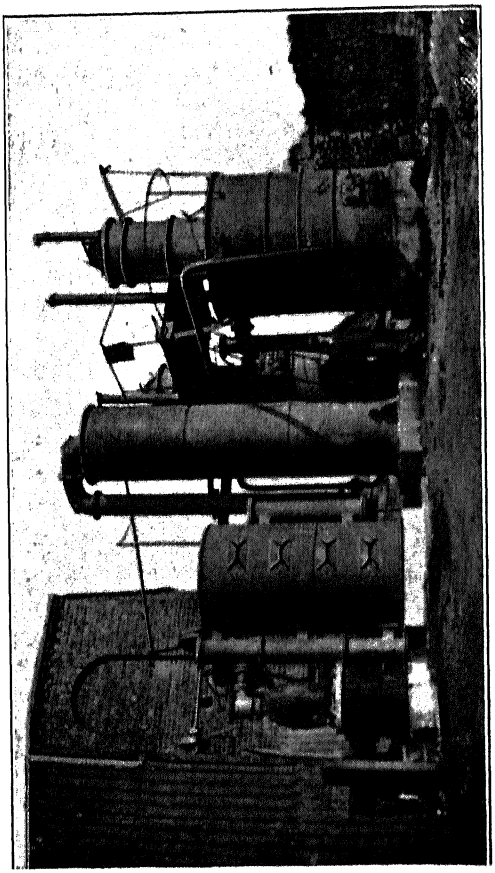


FIG. 10.—Peat Gas Producer Plant at Portadown, Ireland.

B.Th.U. per cubic foot. During a test run of six hours' duration, made in October, 1911, with a load of 250 H.P., the consumption of peat amounted to 2·55 lbs. per B.H.P. hour. From these figures it is calculated that if peat were delivered at the producers at a total cost of 5s. per ton, power could be generated at this plant with an expenditure for fuel of ·062*d.* per B.H.P. hour.

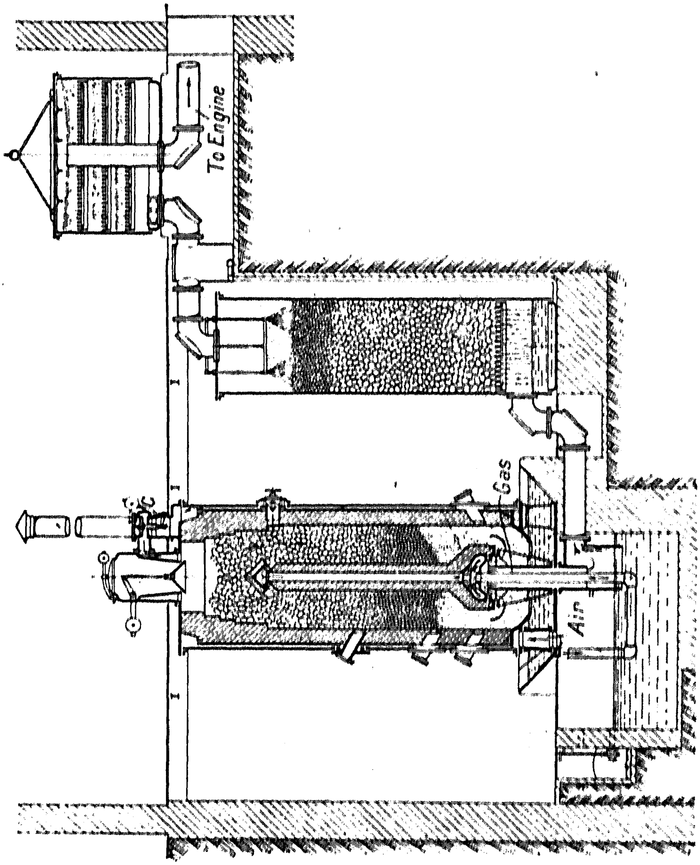


FIG. 11.—German type of Producer for Peat with Ammonia Recovery Plant.

Some difficulties have been experienced at this Portadown plant with the tar, but by increasing the amount of wash-water used for cleansing the gas by spraying, to 7 gallons per B.H.P. hour, this trouble has been overcome and the engines can now be run for three weeks without cleaning the valves.

About 100 tons of peat-tar are produced annually at the Portadown works. As no outlet has yet been found for it the Swedish and German methods of converting it into gas would appear to be the more advantageous, especially as, according to Pegg, 5 per cent. of the weight of the raw peat is recovered in this form.

GASIFICATION WITH RECOVERY OF THE AMMONIA.

The peat-gas power plants described above are worked without recovery of the ammonia, and it is now necessary to consider whether better economic results could be obtained by adding an ammonium sulphate plant to the installation of producers and gas engines. In a paper read before the Liverpool section of the Society of Chemical Industry, in November, 1916, Professor Baly discussed this question at considerable length and many of the figures that follow are taken from his paper. As an example of the amount of sulphate of ammonia that can be recovered from peat, the tests made with producers of the Mond type at the works of the Power Gas Corporation at Stockton-on-Tees may be quoted :—

	German Peat.	Italian Peat.	English Peat.
Moisture (per cent.)	40 to 60	15	57·5
Nitrogen (per cent.)	1	1·58	2·3
Gas from one ton of theoretically dried peat (cubic feet)	35,000	60,000	90,000
Heat-value (B.Th.U. per cubic foot)	150	166	134
$(NH_4)_2SO_4$ per ton of theoretically dried peat (lbs.)	70	115	215

The German engineers, Frank and Caro, have devoted considerable attention to the problem of adapting the Mond producer to the gasification of peat, and a large installation of this modified type of the Mond gas-producer was at work in N.W. Germany on the Schwelger Bog before the War (see Fig. 11). Their method of overcoming the special difficulties caused by the use of peat containing 50 to 70 per cent. moisture is to increase the temperature of the drying zone of the producer to 250° C., this increase being effected by raising the temperature of the air steam blast from 250° to 450° C. According to Baly, this increase gives an intensive combustion of the coke, an increase in the size and temperature of the combustion zone, and consequently an almost quantitative recovery of the nitrogen as ammonia. The total amount of steam used should not exceed, however, half the weight of the peat gasified. Baly gives the following figures as typical of the results obtained with the Mond producer (as modified by Frank and Caro) when working on peat containing 50 to 60 per cent. moisture. One ton of theoretically dry peat gives from 88,000 to 92,000 cubic feet of gas. Of this total 39,000 cubic feet is used in the producers for the air steam blast, leaving 49,000—53,000 cubic feet as surplus, and from this surplus gas 700—750 H.P. hours can be developed. The recovery of nitrogen as ammonia is from 70 to 85 per cent. of that contained in the peat, and the yield of tar is from 3 to 6 per cent.

As regards the cost of the H.P. hour, Baly states that the original figure given when the process was first brought before the public was ·06*d*., but in 1911 figures were published for the Schwelger-Bog plant which showed that all the expenses were paid for by the value of the recovered by-products. At this date the capacity of the plant was 6,000 kilowatts, and each ton of theoretically dry peat produced 1,000 H.P. hours and 90 lbs. of ammonium sulphate. Peat containing up to 70 per cent. water was used in the producers, and the tar obtained was distilled to obtain paraffin wax and neutral oils.

A peat-gas power plant, using a method very similar to the modified Mond method of working, is also in operation at Codigoro, in Italy. The peat, after preliminary drying and crushing, is charged into a producer 30 feet high, having the combustion zone near the bottom. The combustion is regulated by a hot-air and steam jet, and the plant is said to recover as ammonium sulphate three-fourths of the nitrogen in the raw peat, or 170 lbs. per ton. The original plant treated 1,500 cubic feet of peat per day, and produced 50 tons of ammonium sulphate per month, with electrical energy equivalent to 800 H.P. The plant has recently been enlarged, and, according to the latest figures, is now treating 17,000 tons of dried peat annually and producing 10 to 12 tons of ammonium sulphate per day.

Powdered Peat as a Boiler Fuel.

Although powdered peat has not been long before the public as a fuel for steam-raising purposes, many engineers, including the author, believe that this method of utilising peat will expand rapidly, and that it will take the place of the older method of briquetting the peat before burning it for power purposes. The advantages claimed for powdered peat are that it is easily produced, and that it burns with a very hot flame, owing to its high percentage of volatile matter. The method of producing peat powder varies. In Sweden the peat is dug, machined, spread on the bog to dry, and cut into bricks, in the manner customary for briquetting. The air-dried bricks contain 50 per cent. water, and are crushed to a coarse powder in specially built machines; this powder is then dried in rotary driers. In Canada, a novel system of collecting peat powder has been tried, based on the use of pneumatic collecting machines. The cleared and smooth surface of the bog is lightly scored by a harrow, and after a few hours' exposure to wind and sunshine the thin layer of peat powder becomes dried down to 30 per cent. or less of moisture. This dried dust is now collected by air-suction—the collector being operated electrically and mounted on rails. A collector of this type can gather on a favourable day 40 to 50 tons of air-dried peat at a cost of only 6*s*. 6*d*. per ton—and after screening, its moisture contents, if desired, can be still further reduced by artificial drying. A further advantage of peat powder, as a fuel, is that when employed for steam-raising purposes it can be handled and transported more cheaply than bricks, and there is said to be no danger from self-ignition, although this seems doubtful.

The only figures for the efficiency of peat powder as a fuel are those published by Ekelund, who stated that 1·2 tons of peat powder, containing 15 per cent. water, was equal in evaporative effect to 1 ton of the best coal. The cost of producing peat powder in Sweden in 1911 was given as 9*s.* per ton. In 1913, or just before the War, the Finnish Government made a grant of £10,000 to the Turf Fuel Company to aid them in erecting a factory for the production of dust peat, near the railway station at Rychimyaki. This arrangement was based on the experience gained on the Stockholm-Rimbosk Railway, in Sweden, on which line the locomotives, since 1911, had been worked with the new form of fuel. The War, of course, will have stopped these contemplated developments in Finland, but there will now be a considerable expansion of the powdered peat industry in Scandinavia, Northern Russia, Canada and other countries where the climatic conditions are favourable.

CONCLUSIONS.

The above review of the latest trials of peat, as a fuel for generating heat and power, indicates the lines upon which future developments may be expected to occur.

For large central schemes of electric-power generation the production of gas from the partially dried peat in gas-producers of the double-combustion zone type, and use of this gas in large gas engines is certainly the most economical and practical method of utilising the peat. Whether these schemes will be operated with recovery of by-products is a question, the answer to which depends very largely upon the demand and price which can be obtained for these by-products in the localities where the works are situated.

For steam generation and the heating of large furnaces generally the use of powdered peat offers many advantages over the briquetted form of the fuel in addition to the greater cheapness of production, and therefore, in those countries where the surface of the bogs and the climatic conditions favour the production of peat powder, arrangements for producing this form of the fuel in large quantities should be made.

For domestic heating purposes the machine-made brick or briquette is the cheapest, and the writer does not believe that the more elaborate processes used to produce a peat-coke or "tourbon" will be found to pay their working expenses, in the districts where peat must be sold in competition with coal.

As a general rule the simpler the machinery and the lower the cost of its upkeep, the greater is the chance of its successful use for briquette production, and some of the elaborate machines and schemes of the past designed for the production of a domestic fuel from peat have come to grief, because their promoters lost sight of this fundamental principle of success.

CHAPTER III

LIGNITE, BAGASSE AND WOOD WASTE

Lignite (or brown coal) is not found or produced in any quantity in the United Kingdom, but very large deposits occur in Canada and Australia, and there is little doubt that at no distant date these colonial reserves of lignite fuel will become of considerable industrial importance. According to Steuart [1] there are vast amounts of lignite in Alberta, Saskatchewan, and Manitoba, in the Dominion of Canada, and also 1,700 square miles of it in Victoria, in the Australasian continent, so that when the United Kingdom has exhausted her deposits of coal and peat, and is obliged to curtail her manufacturing activities, these other portions of the Empire may take up the *rôle,* and become in their turn the centres of flourishing manufacturing industries.

Already in Germany and in the United States, the beds of lignite which are found in certain districts are being worked and utilised for power purposes on a large scale, and the developments that have occurred in these countries are certainly worth studying, in connection with the further exploitation of the fuel resources of the British Empire.

Chemical and Physical Properties of Lignite.

Lignite is a naturally occurring solid fuel intermediate to peat and ordinary bituminous coal in age, and in chemical properties. As usually found it is earthy in appearance and brown in colour, hence its name of "brown coal." The percentage of water in freshly-won lignite is large, ranging from 30 to 50 per cent., and even after air-drying, the moisture contents are still high and vary from 10 to 20 per cent.

---

[1] *Journal Society Chemical Industry,* February 28th, 1917.

When large lumps of lignite are dried, the escape of the excessive moisture causes them to break up into small pieces, and this "crepitation" detracts from the value of natural lignite as a fuel, except after briquetting or other treatment.

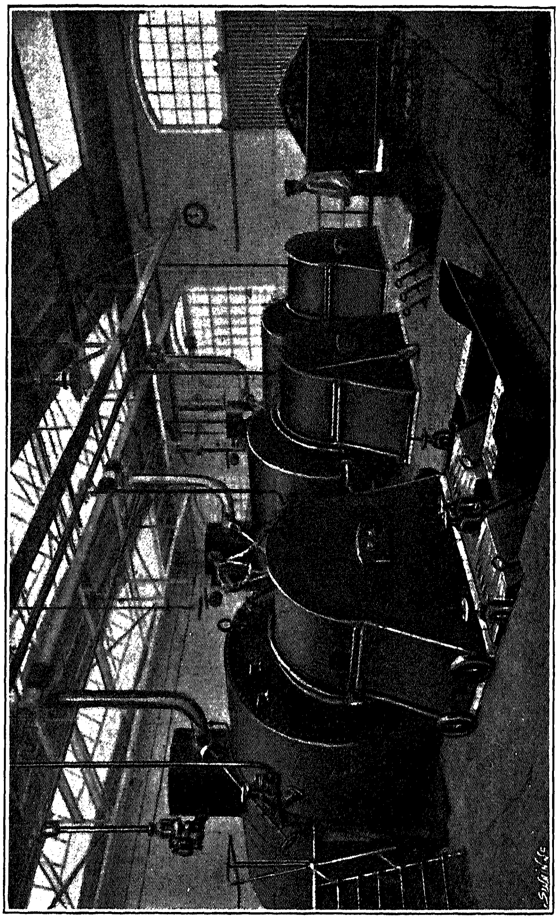


Fig. 12.—German type of Furnaces and Boilers for burning Lignite.

The ash contents vary from 5 to 10 per cent., and the volatile hydrocarbons from 35 to 45 per cent.

Four methods of utilising lignite are in operation in different parts of the world, namely :—

(1) Air-drying and use in the natural state for power generation.
(2) Briquetting.
(3) Distillation.
(4) Gasification.

(1) POWER GENERATION FROM AIR-DRIED LIGNITE.

The electro-chemical works at Bitterfeld, in Saxony, are operated entirely with electric power derived from the very extensive beds of lignite which occur in the vicinity. In fact, the site of these works was purposely chosen by the promoters because it was believed that the cheapness of the power would more than counterbalance the distance of the works from the usual markets for the manufactured goods.

The works here are an offshoot from the original German Electrolytic Soda Works, at Griesheim, near Frankfort, and operate what is known as the *Elektron* process of soda and bleach manufacture.. The fact that these Bitterfeld Works have been greatly extended since their erection in 1894, when the plant was designed for the utilisation of only 3,000 H.P., proves that the successful production of electric power from lignite was quite possible, even under the pre-war conditions of competition, with power derived from coal and water.

Very few details of the works, or of the power plant, have been allowed to appear in print. It is known, however, that the lignite is cut from the beds in which it is found by mechanical cutters or shovels, is subjected to a certain amount of air-drying, and is then carried to the works by an aerial transporter system. No official figures showing the actual results obtained at the power-plant have been published.

The *Zeitschrift des Vereines Deutscher Ingenieure,* however, in February, 1908, published an illustrated description and tests of an installation of four tubular boilers, with step-grates specially designed for operation with lignite, and some details of this plant may be given here, for no doubt it resembles that at Bitterfeld in many respects. Figs. 12

and 13 show a general view of the charging-floor of the boilers, and sectional elevations of the grate respectively. The latter, it will be seen, is sunk below the floor-level, and the lignite is tipped directly into the charging hoppers from the tip-waggons in which it is brought into the boiler-house. A sliding door divided into three sections regulates the admission of the fuel to the grate of each furnace. The angle of the step-grate can be altered from the ground-level. The lower part of the grate is horizontal, and the combustion of the partially consumed fuel is completed on it. The ashes are then allowed to fall into enclosed ash boxes by drawing a horizontal damper. From these boxes they are discharged into small waggons running along the rails below the step-grate. The admission of air during the discharge of the ashes is prevented by this system of removal. The whole of the lower part of the step-grate is enclosed, and the admission of air to the grate is regulated by the levers which open or close the doors in front of the under-furnace space. The air required

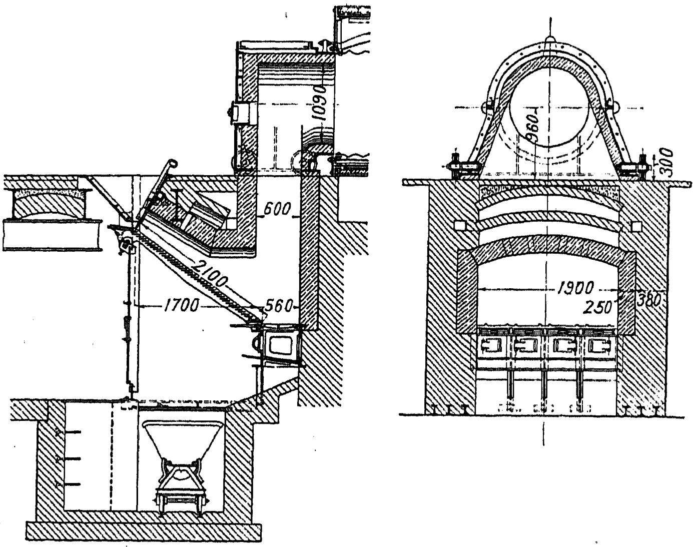


FIG. 13.—German type of Boiler Furnace for Lignite (sectional elevation).

for combustion is drawn through a system of pre-heating stoves. As the use of the step-grate causes the gradual evolution of the gaseous matter of the fuel, little or no smoke is produced, and a secondary air supply, though provided for, is seldom required. Trials carried out with this boiler installation have shown efficiencies of between 67 and 69·7 per cent. when using a fuel having the low heating value of 2,721 kilo.-cals. (equal to 4,897 B.Th.U.). From 2·66 to 3·01 lbs. of water were evaporated per lb. of fuel, and the rate varied from 15·5 to 20·0 kilos. per square metre (3·1 to 4·1 lbs. per square foot) of heating surface. The waste gases contained from 16·1 to 17·2 per cent. CO_2, corresponding to an excess of air only 1·08 per cent. above that theoretically required.

The successful exploitation of the lignite deposits at Bitterfeld has caused this previously unknown and unimportant place to become a flourishing centre of the German electro-chemical and electro-metallurgical industries, and the rapid developments there prove that the products of electric power, generated by burning lignite under steam boilers, are quite capable of competing with those produced from electric power obtained in the more customary manner from coal.

Passing on now to consider American practice and experience, Bulletin 89 of the U.S.A. Bureau of Mines, upon "Economic Methods of Utilising Western Lignites," by E. J. Babcock, contains some very useful information upon the correct methods of burning lignite for power generation. The author of this Bulletin states that "The proper combustion of lignite depends largely upon using a size of coal that will give an abundant air-surface, but, in addition, a good draught should be so arranged that the air can be directed through the burning coal to the best advantage and can easily be controlled and closely shut down, when it is desired to hold the coal at a relatively low heat. The fire-box should be kept reasonably well filled, but the firing should be carried out frequently by the application of thin layers of fuel to the surface of the bed of hot lignite. The ash and clinker should be removed carefully, and at sufficient rate to prevent the accumulation of clinkers. Many firemen fail to get good results in the use of lignite because of uneven firing. The fire is allowed to run low, and then a large quantity of the lignite, much of it in large lumps and carrying a high percentage of moisture, is introduced. The large addition immediately slackens the fire and materially reduces the temperature in the fire-box, and by the formation of considerable vapour reduces still further the temperature of the gases, the heat from which should be left for boiler absorption. By such firing it is impossible to keep a uniform load with a high boiler efficiency, and much loss of fuel is experienced. By using coal of reasonably small size and firing in thin layers frequently, this difficulty is reduced to a minimum."

This view of the conditions required for the proper combustion of lignite is supported by the experience of the Hughes Electric Co., of Bismarck, N. Dakota, a firm which has been using the deposits of this fuel in Dakota as a boiler fuel for some years. According to C. L. Larsen, the chief engineer of this Company, in order to obtain a high efficiency with lignite it is necessary to maintain a high temperature in the boiler furnace, and the propoition of excess air must therefore be cut down to the lowest possible point. Mr. Larsen recommends for burning lignite " a flat sawdust grate with ½-inch round holes. Such grates contain only 15 per cent. air space, but by having small openings a higher air-pressure in the ash-pit can be maintained and the air passes through the small holes and through the bed of fuel at a greater velocity. This produces a high temperature in the furnace, and as the volume is small, the heat is not rushed through the boiler and up the smoke-stack, but is absorbed by the water in the boiler, and a low temperature in the smoke-stack is obtained."

Working under these conditions, he asserts that an evaporation of nearly 5 lbs. of water per lb. of fuel can be obtained from a lignite testing 35 per cent. moisture and 6 per cent. ash, and showing only 7,000 B.Th.U. in the calorimeter. To obtain such an evaporative result, however, the boiler must not be pushed at all above its rated capacity, and only 3 lbs. of water can be evaporated per square foot of surface per hour.

Another American contribution to the subject of lignite is that of Randall and Kreisinger (Bulletin 8 of the Bureau of Mines) upon "The Use of North Dakota Lignites for Power-plant Boilers." The conclusions arrived at by these two investigators were (1) that a large combustion chamber was necessary in order to obtain the best results, and (2) that the gases yielded by the lignites must be completely burned in this chamber and raised to the highest possible temperature before being allowed to come into contact with any of the water-cooled surfaces of the boiler. A Dutch-oven type of furnace was employed in this investigation, and the following is a description of the furnace and its method of operation :—

"The most striking features in the construction of the furnace are the deep-set grate and the contraction of the space between the bridge-wall and the end of the prolonged fire-brick arch. The furnace is designed to work on the gas-producer principle. The solid fuel is gasified on the grate, and the gas passes through the space under the arch into the combustion chamber, where most of the gaseous combustible burns. The necessary air for combustion is added through the openings in the bridge wall. This air is pre-heated to 200° to 300° F. in coils, and forced into the furnace under a pressure of 0·5 to 1 inch of water. The grate is 21 inches below the lower edge of the firing door. The object of this construction is to enable the fireman to carry a thick fuel bed, and still see its condition at the top. The side furnace-door used in removing clinkers is only 7 inches above the grate."

The grate was equipped with rocking-bars to facilitate the removal of ash, and each grate-bar was supported by a 2-inch pipe, through which cold air was circulated. The thermal efficiency of this type of furnace, when used for steam-raising with lignite, was from 55 to 58 per cent., and it is stated that no difficulty was experienced in working up to the full capacity of the boilers. North Dakota lignite has, in fact, been employed with this type of furnace at the pumping plant of the United States Reclamation Service at Willaston, N.D., with good results. Fig. 14 shows sectional elevations of the boiler and furnace.

(2) BRIQUETTING.

The chief centre of the manufacture of lignite briquettes in Germany is at Horren, a small town west of Cologne, the industry at that place having been developed within the last twenty-five years. According to C. A. Davis, who prepared a report upon the subject in 1913 for the U.S.A. Bureau of Mines, there are twenty-six factories producing lignite briquettes in the neighbourhood, and about 20,000 metric tons were manufactured daily during the season of active production at that date. The mines are on the high terraces of a broad shallow valley, the strata of coal are from 230 feet to 400 feet in thickness, and the lignite is brought to the various works by an overhead transporter system. This one district, in 1911, produced rather more than one-fourth of the total German output of lignite briquettes, the largest works having twenty-eight presses, and turning out about 1,600 metric tons of briquettes per day of twenty-four hours. The following description of the method of manufacture, and of the plant at the most recently erected works, is taken from the report referred to above. The brown coal as mined contains 60 per cent. moisture, and, when dried, is dark brown in colour, and easily powdered. The coal on delivery at the briquette factory of the Gewerkschaft "Kohlenquelle" is first crushed and screened, and is then dried in four Schulz driers, each with a capacity of 70 metric tons per twenty-four hours. Each drier consists of a large cylinder of boiler-iron 23 feet in length and 10 feet in diameter, mounted on trunnions, with the main axis inclined about 7 degrees from the horizontal. Inside the outer drum or shell of the drier is a second drum fitted with 366 tubes, each about 4 inches in diameter. The exhaust steam from the engines is admitted to the space around the tubes, under a pressure of three atmospheres, through valves in the trunnions that support the drier. The moist powdered material is fed constantly from the storage pockets into the tubes by means of spiral conveyers, and the rate at which it passes through them is regulated according to its moisture content.

To reduce 60 per cent. moisture down to 15 per cent. requires the fuel to be three-quarters of an hour in passing through the drier. The steam from the lignite is forced through a cyclone chamber by means of fans before being turned into the atmosphere through the escape flues. By this plan the dust, amounting to 3 per cent. of the total material dried, is collected from the escaping steam, and is added to the material to be briquetted. The air in all parts of the factory building is practically free from floating dust, because the dried brown coal is handled entirely in closed conveyers, and is not at any point permitted to escape into the factory. In this way all danger of dust explosions, which in early types of such plants were not infrequent, has been eliminated. The cost of the whole process of drying is about 70 pfennige (or 8·5*d.*) per ton of product.

The briquetting portion of the plant consists of five compound three-cylinder horizontal engines, directly connected with open-mould plunger presses. The cross-section of the plunger and mould of this type of press is lozenge-shaped, and in the single presses is about 7 inches long by 2¼ inches wide. The long axis of the mould is horizontal in the press—in the double presses the moulds are placed side by side, so that the two briquettes formed at each stroke of the plungers issue from the press end to end. The powdered brown coal, containing about 15 per cent. moisture, is fed into the mould from hoppers, and is subjected to a pressure of from 18,000 to 22,500 lbs. per square inch. A pressure equivalent to 300,000 to 400,000 lbs. is exerted therefore on each briquette. The press forms or plates that form the moulds of the briquette presses are made of hardened steel, and are changed when they become so worn that the plunger no longer fits the mould well enough to make good briquettes. The chief cause of the wear is the sand, or other mineral matter, contained in the powdered raw material. The time that these plates last varies from three days to about four weeks, according to the amount of mineral matter present. The briquettes weigh about 1 lb. each. No pitch or binding material of any sort is used in manufacturing them ; the tarry matter liberated from the brown coal by the heat developed in compressing the material serves this purpose. The briquette presses are jacketed and water-cooled. A single press has a capacity of about 70 metric tons of briquettes per twenty-four hours, and requires 120 H.P. A double press takes 200 H.P. The power for driving the plant is obtained from a battery of eight boilers fired entirely by brown coal as mined, and containing 60 per cent. moisture. The boilers together furnish 750 H.P., and supply steam to the engines at a pressure of 180 lbs. In addition to the boilers there is a superheater, in which the steam for the driers is superheated to 300° C. One car load out of three of the brown coal brought to the plant from the mine is sent directly to the feed-hoppers of the boilers. From these hoppers the material is fed by mechanical stokers to the fires, and is burned on step-grates. Each boiler has about 1,300 square feet of heating surface, 270 square feet of superheater area, and 65 square feet of grate area. Only three men are required to attend to the entire battery of eight boilers, one to keep the feed-hoppers filled, shift and empty cars, etc., the two others to attend to the stokers and grates. The briquettes fetch 8*s*. per ton at the factory ; the retail selling price at Cologne in 1913 was 11*s*. per metric ton.

As regards American experience, the U.S.A. Bureau of Mines, in 1908 to 1910, carried out some valuable experimental work with the lignites found in North Dakota, Texas and California, in order to ascertain whether the methods and forms of briquetting press used in Germany, and described above, could be applied with success to these American lignites.

The results of this inquiry are recorded in Bulletin 14,[1] and although the investigation was not completed, sufficient testing had been carried out to prove that many of the American lignites have as high a thermal value as the German ones, and that they can be briquetted upon a commercial scale without the use of any binding material. It has also been proved that, contrary to the generally held opinion, lignites that have been slaked by exposure to atmospheric influences can still be briquetted without a binder. Cohesion and weather tests, which were made with raw lignite and with the finished briquettes, showed that the latter were the superior in resistance to handling and also to weather influences.

---

[1] "Briquetting Tests of Lignite at Pittsburg, Pa.," by C. L. Wright.

With regard to practical developments in America, one of the American technical journals [1] has published a description of a plant erected in 1915 at Denver, Colorado, for the commercial production of briquettes and the recovery of valuable by-products from lignite. The fuel is subjected first to dry distillation in order to obtain gas, light oils, ammonium sulphate, creosote and pitch, while the residue of coke left in the retorts is finally briquetted with the aid of binding materials. The ovens or retorts at this plant are designed to take 10-ton charges, and the heating period lasts two hours at a temperature of 500° C. The yield of by-products at this temperature per ton of raw lignite is stated to be as follows :—Gas, 10,000 cubic feet ; tar oil, 13 gallons ; ammonium sulphate, 2·5 lbs. The pitch, and some other binding material, are employed for briquetting the residue left after the distillation is completed, and the briquettes, or "*carbonets*," as they are called locally, have the following composition :—Moisture, 1·34 per cent. ; volatile matter, 7·60 per cent. ; ash, 7·02 per cent. ; fixed carbon, 84·04 per cent. ; calorific value, 14,061 B.Th.U. They withstand unfavourable weather conditions and rough handling very satisfactorily, and also retain their form when burned, until they are practically all consumed. The Denver Works, as originally planned, were designed for the treatment of 500 tons of raw lignite per day, and the briquetting plant for an output of 25 tons an hour.

The details of this method of treating the Colorado lignites were worked out in the laboratory before the works at

---

[1] *Coal Age*, April 15th, 1916.

Denver were designed or erected, and it is hoped that the very careful preliminary study made of all the scientific data will lead to the foundation of a new and flourishing local industry.

(3) DISTILLATION AND RECOVERY OF BY-PRODUCTS.

A lignite suitable for low temperature distillation is characterised by a high content of bituminous matter. In the absence of this bitumen the fuel is not adapted for the retort process, and is only suitable for direct burning, by either of the methods described in Sections (1) and (2) of this article. One can distinguish roughly between the two classes of lignite by observing closely the changes that occur on heating, and by comparing the specific gravities of the samples. Lignites suitable for subjection to the distillation or retort process melt or soften before ignition and burn with a smoky flame ; they also possess a specific gravity between 0·90 and 1·10, whereas the lignites suitable for direct burning do not soften or melt on heating, and have a specific gravity of 1·2 to 1·4.

The distillation of lignite is carried on in Germany at two centres, namely, at *Halle*, in Saxony, and at *Messel*, near Darmstadt. Steuart,[1] in a paper read before the Edinburgh section of the Society of Chemical Industry, in January, 1917, has given a full account of the process as carried out at these two centres, and has described the methods and apparatus used for the recovery of the by-products. The latter consist of crude oil, containing various hydrocarbons of the paraffin and aromatic series, paraffin wax, and a coke testing about 12,600 B.Th.U. The yield of crude oil at *Halle* is about 18 gallons per ton of lignite, and in that district there are twelve works which distil one million tons of brown coal per annum, and produce 60,000 tons of crude oil and 7,000 tons of paraffin wax. At *Messel* the crude oil is distilled from the lignite in the presence of steam, and the coke that remains in the retorts is dropped directly into gas-producers below. Vertical retorts (covered by German Patent 200,602, of

---

[1] *Journal Soc. Chem. Industry*, February 28th, 1917.

May, 1906) are employed, and are worked continuously, the brown coal being fed into the retort from a hopper closed by a valve. In the upper part of the retort the lignite is dried; the steam produced there is drawn off by an electrically-driven fan. Part of this steam is re-introduced into the retort lower down, in order to keep the temperature at the required low limit, the remainder is used for the gas-producer, which is worked with the coke residue from the retort process. The laboratory distillation of the lignite used at Messel yields 44 per cent. moisture, 7·8 per cent. crude oil, 6·2 per cent. gas, and 36 per cent. of coke; but the latter, as already explained, is used for gas production, and no marketable coke is made. The actual yield of crude oil is about 19 gallons per ton of lignite, and the final products, obtained by distillation of the crude oils, are benzine, solar oil, pale vaseline oil, fat oil, solar scale, red oil, heavy vaseline oil, and paraffin wax.

In America the only distillation works of which full details have been published are those referred to above—as established at Denver, in Colorado, in 1915, for the production of briquettes and by-products from the Colorado lignites. The ovens or retorts here are 36 feet long by 9 feet high by 18 inches wide; the charging period is 2½ hours, and the temperature limit is 500° C. The average yield is 10,000 cubic feet of gas, 13 gallons of tar oils, and 2½ lbs. ammonia sulphate. The gas is used for heating the ovens and also for steam generation, in order to supply the plant with the necessary electric power; the crude oil is distilled and is separated into light oils, heavy oils and pitch. At temperatures up to 150° C., 10 to 14 per cent. of the crude oil passes over to the light oils storage tank, and between 150° C. and 325° C. the heavy creosote oils—which form about 68 per cent. of the total oil—are distilled. The manufacture of briquettes from the lignite coke has already been referred to under "Briquetting," and it is only necessary to add that the works were planned by Mr. C. O. Hoover, of Denver, and that they are owned by the American Coal Refining Co.

A large amount of experimental work upon the distillation of North Dakota lignites has been carried out at Grand Forks by the staff of the College of Mining and Engineering of North Dakota, where a specially designed briquetting and gas-making plant has been erected for the purpose of studying the utilisation of these lignites. The details and results of the investigation are given in Bulletin 89 of the U.S.A. Bureau of Mines,[1] and the following paragraphs from this report summarise the conclusions arrived at :—

"From the results obtained by the methods being developed at the School of Mines, and the substation of the University of North Dakota, there seems little doubt that the briquetting and the production of gas from lignite can in the near future be put on a commercially satisfactory basis. Because of the ease with which the gas is produced, the low price of the original lignite, the value of the residue, and the low price for which it could be sold, if manufactured in a plant used to produce briquettes from the residue, the lignite gas should have a large commercial utilisation for heating, lighting, and power purposes. . . . One ton of the air-dried lignite will produce from a half to two-thirds of a ton of briquettes, in addition to 8,000 or 10,000 cubic feet of gas. The briquettes have about twelve-thirteenths the actual heating value of hard coal, and they can be shipped for considerable distances and still prove profitable. . . . No detailed statements of the cost of operating a large commercial plant are given in this Report, for the reason that the cost per ton of briquettes and per 1,000 feet of gas and other by-products will depend upon a large number of factors, any one of which may materially affect the cost. . . . In general the larger the plant and the more complete the saving of by-products, the smaller will be the cost of production. It is believed that in a carefully constructed and operated plant the saving and utilisation of the various by-products will so reduce the cost of operation as to make the industry commercially practical and profitable. All of the data obtained from the investigations and the operation of the experimental plant indicate that a plant of fair capacity, if so constructed as to economise in the original cost, as well as in the cost of operation, and if operated efficiently and under careful management, should turn out excellent commercial products at a cost that would admit of a fair profit."

---

[1] "Economic Methods of Utilising Western Lignites," by E. J. Babcock.

This Bulletin contains a full account of all the experimental work carried out in order to determine the best conditions for the gasification of lignite. The relation between the moisture contents of the raw lignite and the yield and thermal value of the evolved gas was closely studied, and the effects of temperature variations were also examined and tabulated.

The statement below, prepared from the figures presented in the Bulletin, shows the average results of the gasification tests made in this experimental plant, with twenty-five representative samples of United States lignites.

Gas.

Yield per ton.	Cal. value per cubic ft.	Percentage Composition.
11,038 cubic feet ..	396 B.Th.U. ..	40·1 H; 20·09 CO; 15·31 CH_4; 10·48 CO_2; 9·98 N.

Coke.

Yield per ton.	Cal. value.	Percentage Composition.
1,092 lbs. ..	11,838 B.Th.U. ..	75·52 C; 7·57 Vol. matters; 15·91 ash; 1·98 S; 1·00 H_2O.

(4) Gasification without Recovery of By-products.

The fact that many lignites are too poor in their contents of bituminous matter to render distillation profitable, accounts for some of the past failures that have occurred with plants erected for that purpose. Lignites of this type, however, are quite suitable for gasification, without attempting the recovery of the tar or ammonia, and there are many places where gas-producers of the type designed for use with bituminous fuel would prove of great value in connection with the utilisation of lignite deposits. Small plants of this kind are quite as efficient as large ones, for there is no necessity to design the plant on the large scale that is required for successful by-product recovery. Whether the gas obtained from these lignite gasification plants would be best used to raise steam, or for direct power production in gas engines would depend upon local conditions and requirements.

In New Zealand, it may be noted, the use of lignite producer-gas for power production is quite common in the electric power stations, and the natural moisture contents of the raw lignite renders it quite possible to work the producers without steam. Producers of this type, in which the upper part is used as a gas retort and the lower part as an ordinary producer, have been designed by Ziegler, Zwingenberger, and others, and have been employed for peat and lignite gasification with success in Germany and Austria.

BAGASSE: CHEMICAL AND PHYSICAL PROPERTIES.

"Bagasse" is the technical name for the tough fibre that is left after milling sugar-cane for extraction of the sugar. The proportion of combustible matter in this residue varies considerably in different districts, ranging from 35 to 60 per cent., while the water contents and ash make up the balance of 40 to 65 per cent. In Louisiana the average composition is as follows :—Fibre, 40 per cent. ; sucrose and other sugars, 7 per cent. ; moisture, 53 per cent. The heat value of dry bagasse is found by experiment to be 8,300 B.Th.U. The proportion of the total heat which can be rendered available in practice for power generation depends upon the percentage of water which remains in the bagasse when burned. According to Freeland,[1] the average Louisiana product has a calorific value of about 8,300 B.Th.U. per lb. of dry bagasse, and from 3,620 B.Th.U. gross (with bagasse containing 56·7 per cent. moisture) to 4,800 B.Th.U. (containing 42·8 per cent. moisture). The net heating values are respectively

---

[1] *Journal American Society Mechanical Engineers*, November, 1917, and *Power*, December 4th, 1917.

2,200 and 3,350 B.Th.U., and 1 lb. of wet bagasse will evaporate from 2 to 3½ lbs. of water from and at 212° F.

Professor Kerr found that at a certain Louisiana sugar-house the bagasse from 1 ton of cane generated from 1·16 to 1·44 boiler H.P. The bagasse from a 1,000-ton house will generate, therefore, a total of 1,160 to 1,440 B.H.P. hours per twenty-four hours, and it would require about 60 tons of coal per day to do the same work. Professor Kerr further stated that in Louisiana 16 per cent. of the total heat generated by the combustion of 1 lb. of bagasse was required to evaporate the moisture present in the bagasse. As about 14½ per cent. of the moisture in bagasse could be removed by drying, the dry fuel had a heating value 55 per cent. greater than the wet. For this reason the methods of burning bagasse are now being improved, and in the larger sugar-cane factories of Cuba and Hawaii it is subjected to a preliminary drying before entering the combustion area of the grate.

METHODS OF BURNING BAGASSE.

The grate surface must be small in furnaces intended for burning the waste sugar-cane since the rate of combustion is high, rising at times to 300 lbs. per square foot of grate surface per hour. In some of the recently installed 500 H.P. boilers the grate area is only 25 square feet, whereas a coal-fired boiler would require quite three times that area for the satisfactory combustion of the same equivalent weight of fuel. In other respects the grates and methods used resemble those employed for coal with high volatile matter contents. Mechanical stokers are also now being tried, since with stokers of the coking type the bagasse can be subjected to a preliminary drying, and its heat value improved before actual combustion occurs. When used with these stokers the fuel is spread out upon the front portion of the stoker, and the rate of feed is regulated so as to obtain the maximum heating effect. Furnaces of the step-grate type are also being used in some of the more up-to-date sugar mills, for the air supply is more easily controlled with this type of grate.

WOOD AND SAW-MILL REFUSE.

Saw-mill refuse is one of the staple fuels for steam-power plants in certain of the timber-felling districts of the United States, Canada and Australia, and in Europe a considerable amount of power is developed from the wood-shavings and refuse produced by the wood-working factories, where boxes and packing-cases are made by machinery on a large scale. The waste material produced in these mills and factories may be burned, either directly under steam boilers, or it may be gasified in producers, and the gas employed in gas engines.

As examples of the type of furnace used in U.S.A. and Canada for burning saw-mill refuse under steam boilers, the equipment at the plant of the Portland (Oregon) General Electric Co., and at the Rockwell Manufacturing Co., New York, may be cited.

The boilers at the former plant are provided with external furnaces of the Dutch-oven type. These furnaces are provided with charging-holes, into which the sawdust and wood-waste are tipped from the conveyers which transport them from the timber yards of the surrounding locality, and the Dutch-ovens are kept completely filled in order to prevent air leakage. The two generating stations of the company in Portland equipped with this type of wood-burning plant consume 100 to 150 box loads of refuse (equivalent to 20,625 cubic feet) per day of twenty-four hours, and the average evaporation attained is 10,500 lbs. water per 200 cubic feet of cut fuel. Assuming that 1 cubic foot of the refuse weighs 15 lbs., this equals an evaporation of 3·5 lbs. water per lb. of wood, which is quite a good result under the circumstances. The calorific value of wood varies from 8,300 B.Th.U. to 9,000 B.Th.U., and its maximum evaporative value in practice is 5 lbs. water per lb. of fuel.

At the Rockwell Manufacturing Co.'s plant there are two 125-H.P. horizontal tubular boilers installed, each 66 inches by 18 feet, with 1,250 square feet of heating surface, and working at 150 lbs. steam pressure. A blower fan system of collection for the wood-working waste is used in order to collect and transport it to the boiler room. From the storage place on the boiler-room roof the waste fuel falls by gravity into the shutes that carry it to the furnaces. The cost of generating the kilowatt-hour at this plant is 0·79 cent, but no figures are available to show the evaporation obtained per lb. of wood refuse.

An English plant for burning waste from joiners' shops and saw mills is illustrated in Fig. 15, and was designed and erected by Meldrums, Ltd. The equipment consists of a destructor with three grates, provided with both top and front feeding arrangements, and a marine-type three-flued boiler, having 2,500 square feet of heating surface. The grates of the furnace are of the makers' standard type for destructors, each of 25 square feet area, and forced fan-draught is employed for burning the refuse. The plant was guaranteed to burn 40 tons of refuse per twenty-four hours, but this limit has been largely exceeded. The following are the more important figures of a test run of six hours with the plant, in May, 1918:—

Fuel consumed	29,456 lbs.
,, ,, per hour	5,123 ,,
Water evaporated	6,800 gallons
,, ,, per hour	1,182 ,,
,, ,, per lb. fuel	2·3 lbs.
,, ,, from and at 212° F.	2·6 ,,
Average steam pressure	85 ,,

The waste consumed in this test consisted of shavings and scrap timber, etc., from the saw-mills and joiners' shops, with ashes, tar and other refuse from the gas-producer plant, and also general works' refuse.

As regards the gasification of wood-refuse, Fernald, in the Bureau of Mines paper referred to below,[1] describes and illustrates two forms of gas-producer specially designed for use with this class of refuse. Figs. 16 and 17 show the plan and lay-out of an up-draught and down-draught producer, respectively. When wood-tar is in demand and the price is good, it is no doubt the better system to extract the tar by cooling and scrubbing the gas before it is used for power generation purposes, and in this case an up-draught producer is the type required (see Fig. 16). In many cases, however, especially where the plant is far removed from centres of population and industry, the tar, if recovered, would not command a remunerative price, and in these cases a down-draught producer, which decomposes and converts into carbonic oxide and hydrogen gas the constituents of the tar, is the most satisfactory and economical (see Fig. 17). The amount of tar recoverable, of course, varies greatly with the character of the wood refuse and the temperature at which the producer is worked, and the latter is generally governed by the percentage of moisture present in the wood when charged into the producer. A producer using maple, pine, spruce and pitch-pine refuse, yielded 60 gallons of tar per ten hours shift, the gas obtained being employed to generate 180 H.P. and the fuel consumption being 3¼ lbs. wood-refuse per H.P. hour.

---

[1] Technical Paper, No. 123, 1915.

The most interesting American development of a waste-wood gas-producer for power generation, however, is that described by Trump in the issue of *Power*[1] named below, since the gas, in this case, was being used for the first Humphreys type of pump that has been erected and worked in the United States. A 300 H.P. down-draught wood gas-producer of the Akerlund type has been installed on the S. Bedell Moore Estate at Del Rio, Texas, and the material gasified is the "mesquite" wood obtained by clearing the land which this Humphreys pump is to irrigate. The following figures were obtained in a test run with this producer and pump:—

Gas generated per lb. of wood .	54·7 cubic feet.
Heat value of gas	114·5 B.Th.U. per cubic foot.
Wood used per H.P. hour . . .	1·76 lbs.
Wood consumed per square foot of grate area	20·8 "

---

[1] *Power*, December 1st, 1914, p. 767.

The Humphreys pump, of course, stands in a class alone, and the efficiency obtained in this case is higher than with the ordinary type of gas engine. There are, however, many forms of vegetable and wood-waste which might be used profitably for power generation, if first gasified.

According to Fernald,[1] manufacturers are now designing producers specially for gasifying the waste fuels of this type, and with reasonably dry raw material for feeding the producers the consumption of wood has been reduced to 2 lbs. per B.H.P. hour, as generated by the gas engine. The figures for the best results yet attained with these various kinds of wood-waste, when gasified in producers and the gas used in gas engines, running at full load, are as follows :—

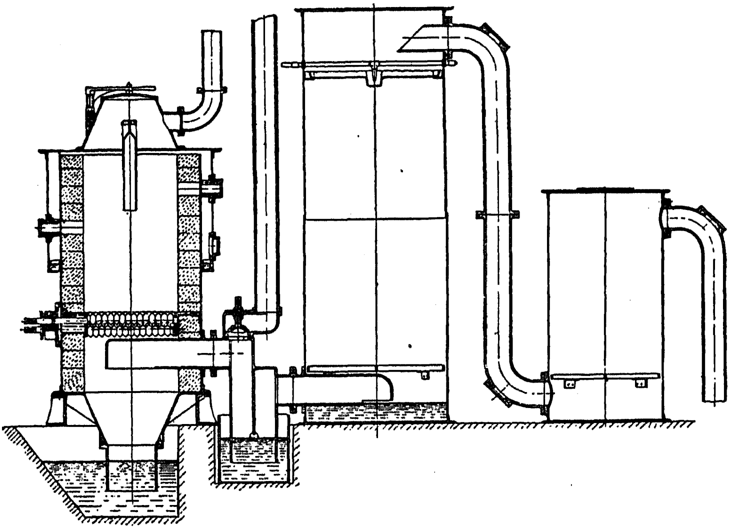


FIG. 17.—Down-draught Gas-Producer for Wood-Refuse and similar Fuels.

Box blocks	2·15 lbs.
Mulga scrub	2·30 ,,
Pine shavings and blocks	2·31 ,,
Jarrah wood, sawdust and shavings . .	2·40 ,,
Spent tan bark (dry)	3·13 ,,
Sawdust	3·50 ,,
Spent tan bark (wet)	4·50 ,,

---

[1] U.S.A. Bureau of Mines. Technical Paper, No. 123 : "Note on the Use of Low-grade Fuels in Europe."

CHAPTER IV

COKE AND COKE-BREEZE

THE War has altered many old-established maxims in our industrial and economic life, and amongst the time-honoured beliefs that have been thrown overboard is the idea that coke and coke-breeze are unsuitable fuels for steam generation. The difficulties of burning coke or coke-breeze in the ordinary type of boiler furnace, provided only with natural chimney draught, had, of course, something to do with the existence of this idea. Every different type of fuel, however, requires special conditions for its complete combustion under steam boilers with efficient use of the heat generated. The fact that coke and coke-breeze could not be burned satisfactorily in furnaces designed and primarily intended for the combustion of bituminous coal, was no proof that they could not be completely burned with high efficiencies under proper conditions, namely, those suited for fuels high in ash and fixed carbon, but low in their percentage of volatile matter.

The more careful study of the problems of fuel combustion in recent years has shown that practically every variety and type of combustible material can be burned, and its heat value converted into the thermal energy of steam, provided that the combustible matter exceeds 65 per cent., and that the furnace is correctly designed and the air-supply properly distributed and proportioned to the needs of the fuel. Materials which have for many years been regarded as waste trade products are now being impressed into the service of the steam producer, and the combustion of coke and coke-breeze is in reality a much simpler problem than the burning of "towns' refuse," or of "bagasse" and other vegetable wastes for power purposes. But the technical side of the problem is only one aspect of it, and the relative price of coal and coke in the past has also had much to do with the neglect of the latter as a fuel for steam boilers. The War has led to a considerable increase in the demand and in the price paid for coal, while the production of coke has been enormously increased, owing to the great demand for benzol, toluol, and other valuable by-products of the distillation of coal. In many coal and coke-producing districts, therefore, the price of coke and coke-breeze has remained steady or has actually fallen, while that of coal has increased, and the relative values of coal and coke have been altered in favour of the latter fuel. It is highly probable that this altered economic relationship will continue now the War is over, for the increase in the labour charges of mines and railways is likely to be permanent, and coal will remain at its present high level of cost for many years to come.

THE CHEMICAL CONSTITUTION AND CALORIFIC VALUE OF COKE AND COKE-BREEZE.

Coke, of course, represents the non-volatile portion of ordinary coal after this has been subjected to heat in the absence of air, and it may be regarded, therefore, as containing only the fixed carbon and the mineral matter, or ash, of the original fuel. Nearly all forms of coke contain, however, a small amount, varying from 1·0 up to 5·0 per cent., of volatile matter, due to the incompleteness of the coking process; the percentage being lowest in the hard cokes produced by the high temperature ovens for blast furnace work. The soft porous cokes obtained by low temperature distillation, as, for example, "coalite," contain, on the other hand, from 5 to 10 per cent. of volatile matter, and do not come within the scope of the present article. Coke-breeze represents the screenings from the lump coke after this has been drawn from the retorts and has been quenched by water and crushed to the various sizes required for the market. It contains, as a general rule, a higher percentage of ash and moisture than the lump coke from which it has been obtained. From the steam-raisers' point of view, therefore, the chief impurities of these forms of fuel are the moisture and ash.

THE MOISTURE IN COKE AND ITS EFFECT UPON COMBUSTION.

Both coke and coke-breeze contain considerable percentages of mechanically held moisture, due to their physical structure and to the methods of cooling adopted in their manufacture by quenching with cold water. Contracts for either form of fuel should therefore specify a limit of 6 per cent. for the allowable amount of this impurity. The disadvantage of using coke or coke-breeze with higher percentages of moisture than 6 per cent. is, that this water has all to be converted into steam and driven off before the coke can be ignited, and since it escapes in the form of aqueous vapour with the waste gases, it carries off a large amount of latent heat which cannot be recovered even in the economisers. Experimental steam-raising trials of coke and coke-breeze containing varying degrees of moisture, at the Buenos Aires Tramway Power Station, proved that a 10 per cent. rise in moisture caused a 24 per cent. increase in the fuel bill.

THE ASH IN COKE.

The ash in coke and coke-breeze varies greatly, since it represents all the mineral matter of the original fuel in a more concentrated form, and if this original fuel has been a bituminous slack, or coal of poor quality, the ash percentage in the coke or coke-breeze may rise to 20 or even 30 per cent. Lump coke of good quality, however, should not contain more than 6 to 10 per cent. of ash, and contracts should have the latter limit inserted as the maximum allowable percentage. Coke-breeze will naturally contain a higher percentage of ash, and up to 20 per cent. may be expected to occur in the deliveries of this form of fuel. Should this limit be exceeded, the breeze should be rejected, for a fuel containing over 20 per cent. ash, and over 10 per cent. moisture, will not yield much heat of practical value for power purposes, when burned under steam boilers. The following are typical analyses of coke-breeze, with figures for the gross and net calorific values, as determined by laboratory methods. It may be noted here that the calorimeter determinations of coke and coke-breeze will always yield considerably higher values than can be obtained in practice, owing to the fact that they are tested in the dry state. The necessary deduction that must be made for the heat lost in drying the fuel is shown in column 4 below, and is arrived at by calculating the thermal units required to convert into steam the water contained in 1 lb. of the fuel as fired.

TESTS OF COKE-BREEZE.

No.	Per cent. moisture.	Per cent. ash.	Per cent. volatile.	Losses through moisture in B.Th.U.'s.	Calorific Value.	
					Net, B.Th.U.'s.	Gross, B.Th.U.'s.
1	19·43	22·16	5·07	2,468	9,053	11,521
2	16·92	21·16	2·50	1,751	9,743	11,494
3	12·50	26·62	5·63	1,493	9,695	11,188

THE CONDITIONS OF COMBUSTION AND FORMS OF GRATE REQUIRED.

The above analyses prove that coke and coke-breeze contain larger amounts of moisture and ash than ordinary coal, and that the percentage of fixed carbon in the combustible portion of the fuel, when allowance is made for this high ash percentage, approaches that of anthracite. The conditions required for the successful combustion and utilisation of the heat generated by coke and coke-breeze are therefore similar to those obtaining with anthracite fuel, and are :—(1) Artificial or forced draught ; (2) close approximation of the heat-absorbing surface to the glowing mass of fuel, and (3) facilities for dealing with the large amount of clinker and ash. As the volume of hydrocarbon gas given off by the fuel is comparatively small, the need for large combustion spaces and for the supply of secondary air is non-existent, the conversion of the carbon into carbon-dioxide gas occurring chiefly on the bars of the grate.

For these reasons the marine, Lancashire, or Cornish type of boiler is more suitable than the water-tube boiler for burning coke and coke-breeze, and very little adaptation of the ordinary internally-fired boiler furnace is required to fit it for use with the new fuel.

If it be desired to burn the coke or breeze on some form of mechanical stoker under a water-tube boiler, it is necessary to mix it with ordinary fuel. In the last portion of this chapter some figures are given showing the economy of this method of burning.

The maximum proportion of coke which can be burned in this way, however, is 50 per cent., and where it is necessary or desirable to exceed this proportion, the grate and conditions of draught must be altered to meet the new requirements. For use either alone or mixed with bituminous coal the coke must be broken to small lump size—say, 1 inch to 1½ inch cubes—by special cutters, and a fire-bed of not more than 6 inches to 8 inches thickness should be maintained.

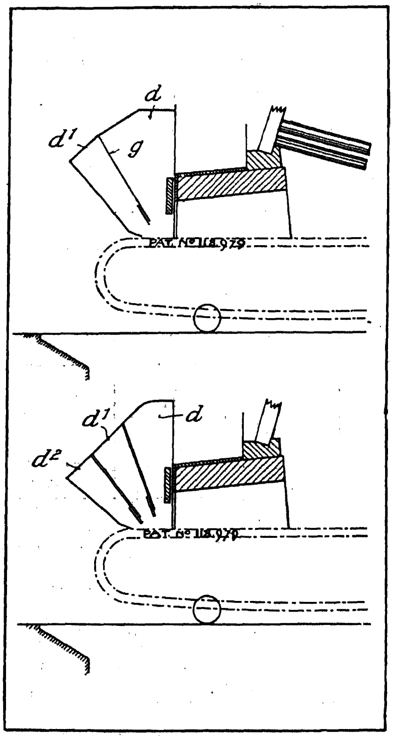


FIG. 18.—Nicol & Schofield's "Sandwich" Feed for Boilers.

When burning a mixture of coal and coke, or coal and breeze, it is very important that the fuel should be well mixed, and in the case of lump fuel that the cubes should be similar in size.

A method of burning the mixed fuels upon chain-grate stokers has been patented by Messrs. Nicol & Schofield (Pat. 118,979 of 1918), and is known as the "Sandwich" system. Fig. 18 shows diagrams of the apparatus, and

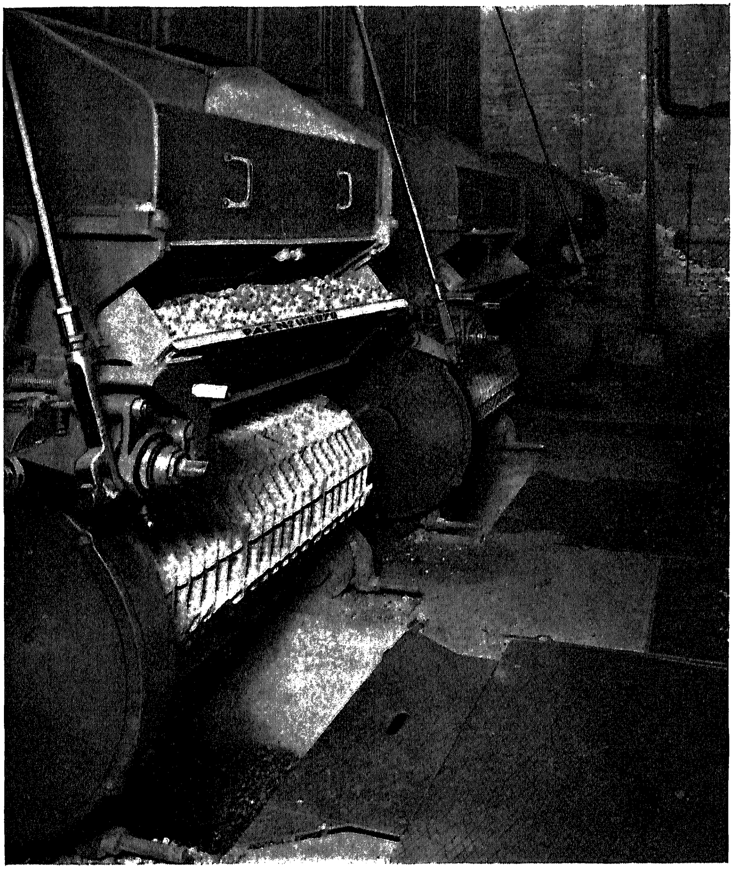


FIG. 19.—Nicol & Schofield's "Sandwich" Feed.

Fig. 19 shows its application to the boilers of an important London power station. As shown in the Figures, the method consists in adding one or more auxiliary hoppers to the usual equipment of the chain-grate stoker, the main supply of fuel being provided by the hopper marked "d," and the auxiliary supply by the hoppers marked "d¹" and "d²." The main or inner hopper then delivers a layer of bituminous or flame-producing fuel *on the top of the* coke or coke-breeze which is fed on to the grate by the auxiliary or outer hopper, and the relative amount of the two fuels can be regulated at will by regulation of the feed slides. The arrangement has been used with success for burning mixtures containing 50 per cent. of coke under natural draught, and the following are comparative figures showing the results obtained at one of the Pumping Stations of the London Hydraulic Power Co. :—

	Test No. 1. Coal and Coke.	Test No. 2. Coal only.
Calorific value as fired . .	11,138 B.Th.U.	12,150 B.Th.U.
Fuel consumed per square foot per hour	30·66 lbs.	31·66 lbs.
Ash and clinker, actual . .	16·22 per cent.	12·7 per cent.
Average steam pressure . .	178 lbs.	179 lbs.
Super-heat temperature . .	486° F.	490° F.
Temperature at boiler damper .	565° F.	568° F.
Water evaporated per hour .	10,505 lbs.	8,747 lbs.
Water evaporated per hour per square foot of heating surface	5·22 lbs.	4·35 lbs.
Water evaporated per lb. of fuel as fired, from feed temperature	7·18 lbs.	5·76 lbs.
Water evaporated from and at 212° F.	9·22 lbs.	7·44 lbs.
Efficiency, boiler and super-heater	69·9 per cent.	53·12 per cent.
Efficiency, boiler with economiser	79·96 per cent.	60·98 per cent.
Draught over fire . . .	·25 inches	·25 inches.

Since coke is not readily ignited except by contact with glowing carbon, the fires must be started with ordinary bituminous coal, and when the volatile gases have distilled off, and only red-hot embers remain on the grate-bars, the firing with coke can commence.

No hydrocarbon gases are evolved from coke on heating ;

the air admission is therefore entirely from below the grate, and all openings and grids by which secondary air has been admitted above the fuel or behind the bridge should be closed. As coke occupies twice the space of ordinary coal, weight for weight, and its calorific value is some 10 per cent. less, it follows that rather more than twice the bulk of coke must be burned on the same grate area in order to obtain the same evaporative effect. This rate of combustion demands in most cases closed ashpits and forced draught.

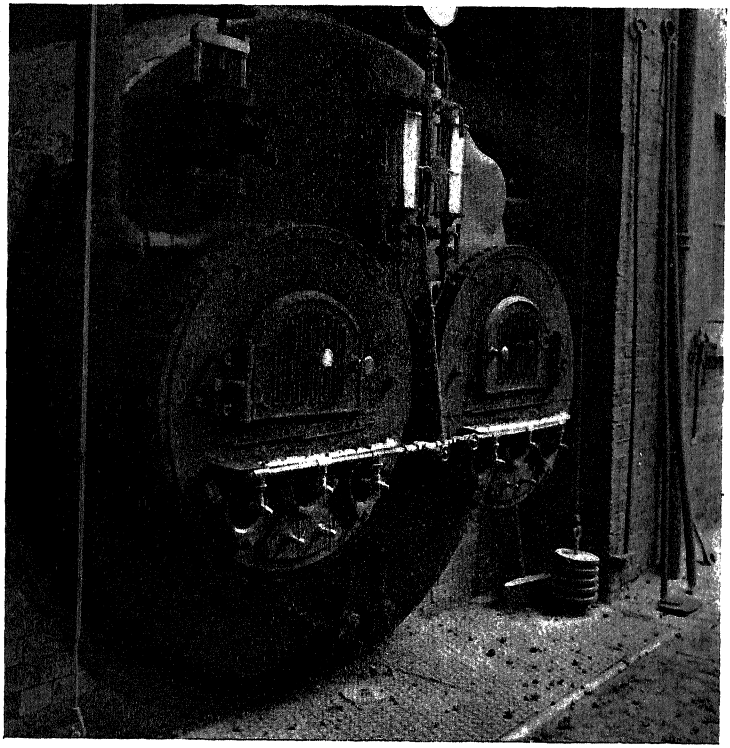


FIG. 20.—Nicol's Steam-jet Forced Draught Apparatus for burning Coke.

Fig. 20 shows a form of steam-jet forced draught apparatus designed specially by E. W. L. Nicol, of the London Coke Committee, for burning coke on the grates of an ordinary

Lancashire boiler. The blowers are easily detached and are thus removable from one boiler to another as occasion demands. With this apparatus coke-breeze can be burned alone, with satisfactory results.

If breeze and lump coke are being burned together, it is well to have transverse bars instead of longitudinal ones since these check the liability of the fine ash from the breeze to be carried away into the side flues of the boiler. When transverse bars are used in the furnace, however, they must be bedded at the ends where they approach the boiler plates in some refractory cement, otherwise "blow-pipe" action may occur at these points and the plates suffer injury.

As regards the rate of combustion possible with coke, when a good natural chimney draught exists, the rate of burning can be raised to 15 lbs. or 20 lbs. per square foot of grate area per hour. With forced draught, the rate can be increased to 30 lbs. per square foot per hour. A grate area of 33 square feet—that of the ordinary 7-foot diameter Lancashire boiler—will thus suffice to burn 990 lbs. of coke per hour, and assuming that 8 lbs. of water are evaporated per lb. of coke, the evaporative effect will be 7,920 lbs. of water per hour.

When coke-breeze or coke-ash containing over 30 per cent. of incombustible matter is to be burned, some form of external furnace of the Dutch oven type becomes necessary for its complete combustion, and in this case the advantages offered by the internal fire-boxes of the marine and Lancashire type of boiler are lost. Forced draught will still be necessary to burn the fuel, and the radiant heat from the furnace can be utilised by means of hollow walls for heating the air before it is drawn into the fan or steam jet—but the heat of the gases issuing from this type of furnace can be best utilised in the water-tube type of boiler. Under-feed stokers are sometimes used with this type of furnace—but as the proportion of ash in the fuel rises, the difficulty of obtaining anything like complete combustion of the carbonaceous matter with mechanical stokers increases.

With either type of furnace, when hand-fired, great care is required to avoid accidents from back-firing or from explosions in the boiler flues, due to the accumulation of carbon monoxide gas when the draught is cut off for cleaning and clinkering the fires. In order to minimise the danger from these causes the following precautions may be taken :—(1) Swivel dampers should be substituted in the side flues for vertical drop dampers, and these should be worked with link rods and a lever from the boiler front ; also the side flues should be inspected and cleaned frequently, to prevent any blockage of flue dust or soot at the foot of the swivel dampers. (2) An excessive depth of fuel bed is contributory to the accumulation of explosive gases in the flues at such times, and a depth of 10 inches should never be exceeded. (3) The safety plugs inserted in the ends of the flue walls should not be blocked by heavy iron tools or implements, but should have a free egress if explosions should occur in the flues.

Since the temperatures attained locally in furnaces fired entirely with coke or breeze under forced draught are much higher than in ordinary coal-fired furnaces, some trouble also may be experienced by burning away and failure of the fire bars. If this occurs the admission of steam to the ashpit under the grates may be the only practical remedy, unless some system of water cooling be adopted. If steam jets are used for creating the draught, this danger is already provided for ; but where fan draught is employed a steam supply pipe to each closed ashpit is desirable for use when required.

The correct regulation of the air supply to coke-fired boilers and furnaces is not more difficult than that to coal-fired furnaces, but there is no smoke to warn the firemen when the air supply is deficient—and with both types of fuel constant testing of the waste gases is an essential of good management and of high efficiencies.

Under scientific management, however, it is possible to obtain a higher average percentage of CO_2 in the waste gases with coke than with ordinary bituminous coal, and this means that the chimney losses of heat in the exit gas are reduced considerably and that a higher efficiency is obtained from the fuel.

The further advantage of smokelessness is, of course, a considerable one, especially in those industrial centres where the smoke inspector is active, for under no conditions of neglect can coke-fired boilers and furnaces produce black smoke.

ACTUAL RESULTS OBTAINED WITH COKE AND COKE-BREEZE FIRING.

I. A small Electric Supply Station in the North of England employed a mixture of slack and coke-breeze in equal proportions upon a chain-grate stoker, with a water-tube boiler, successfully for some months during the War.

The slack cost 16*s.* 6*d.* per ton, delivered at the generating station, while coke-breeze from the local gasworks was obtained at the generating station at a cost of only 6*s.* 1*d.* per ton. The average price of the mixed fuel per ton as charged into the hoppers of the chain-grate stoker was therefore 11*s.* 3½*d.* per ton. The day load at this station is taken by a Diesel oil engine, and the boiler is only worked at night, from dusk to midnight. The results obtained with the two fuels are tabulated below :—

	Slack alone.	Mixed fuel.
Date of test	Nov. 13th, 1914.	Oct. 10th, 1916.
Duration of test . . .	4 hours.	4 hours.
Calorific value of dry fuel in B.Th.U.	13,168	12,178
Price per ton delivered in the works	16*s.* 6*d.*	11*s.* 3½*d.*
Moisture in fuel . . .	7·68 per cent.	10·09 per cent.
Lbs. of fuel used . . .	4,027 lbs.	4,704 lbs.
Lbs. of water evaporated .	31,531 lbs.	30,800 lbs.
Water evaporating per lb. of fuel	7·83 lbs.	6·55 lbs.
Draught	½ inch.	½ inch.
Cost of evaporating 1,000 gallons of water	9*s.* 5½*d.*	7*s.* 9*d.*

This shows a saving in fuel costs of 1*s.* 8½*d.* per 1,000 gallons of water evaporated, or 18 per cent. in favour of the mixed fuel. It is noteworthy that the draught was the same in both tests, and that the total output of steam was only slightly less with the coke-breeze mixture.

II. The engineers of the Buenos Aires Tramway Power Station have made a large-scale trial of coke and coke-breeze for firing their boilers, and have allowed Messrs. Beatty and Smith to publish the results obtained, in the paper named below.[1] Ten thousand tons of coke were burned during the trial, containing on the average 13·5 per cent. ash and 13 per cent. moisture. The following are the average results obtained from the fuel :—

Water evaporated per lb. of fuel .	5·7 lb.
Water evaporated per lb. of fuel from and at 212° F.	6·72 ,,
Fuel used per kilowatt hour . .	3·675 ,,
Boiler efficiency	57·6 per cent.

As the cost of the coke is not given, the comparative costs of firing with coal and coke cannot be calculated, and in this respect the results are not so useful as those given in the preceding table. The best results at Buenos Aires were obtained with a large delivery of coke that contained only 6 per cent. moisture. This gave an evaporative effect of 7·9 lbs. of water from and at 212° F. per lb. of fuel, during trials extending over one month, corresponding to a boiler efficiency of 62 per cent.

When the moisture in the coke rose to 20 per cent. the boiler efficiency fell off to 58·6 per cent. As already stated, a 10 per cent. rise in the moisture contents of the coke burned at this station caused a 24 per cent. increase in the weight of fuel used, for not only had more coke to be handled to obtain the same amount of combustible, but a greater portion of the heat generated was employed in evaporating the water.

III. The chief engineer and fuel expert of the London Coke Committee, in a paper read before the London District Gas Association, gave the results of comparative tests made with coal and coke firing on two Cornish boilers, in February, 1916.[2] The tests were made in London, which accounts for the fact that the relative prices of coal and coke-breeze are much higher than in Test I., and that the saving effected by the use of the cheaper fuel rises to 34 per cent. The substitution of forced draught for natural draught, and the maintenance of a high CO_2 average would no doubt account for the marked increase in the efficiency of the boilers when worked with coke and coke-breeze.

---

[1] *Electrical Review* (New York), April 14th, 1916.

[2] *The Gas World*, April 1st, 1916.

Fuel Test, February, 1916.

Fuel tested	Bituminous coal.	Gas coke.	Gas coke and coke-breeze.
System of draught	Natural draught.	Blowers.	Blowers.
Cost per ton delivered .	25*s.*	25*s.*	17*s.* 6*d.*
Duration of trial, hours .	6·50	7·25	7·66
Type of boilers (two) .	Cornish	Cornish	Cornish
Total grate area, square feet	58	58	58
Amount of fuel used, lbs.	6,720	7,500	4,200 coke, 4,200 breeze
Fuel burned per square foot grate area per hour, lbs. . . .	16·1	16·1	17·1
Water evaporated, lbs. (actual) . . .	45,950	65,000	59,200
Water from and at 212°F. per lb. of fuel . .	7·74	9·80	7·99
Cost per 1,000 gallons evaporated . .	14*s.* 5*d.*	11*s.* 8*d.*	9*s.* 5*d.*
Per cent. CO_2 . .	Not taken	16·0	16·25
Net working efficiency of plant . . .	70·72 p.c.	85 p.c.	80·9 p.c.
Financial saving effected by adopting coke fuel and forced draught .	—	19 p.c.	34 p.c.

The author exhibited at this meeting models of the steam-jet forced draught apparatus used in these tests, and stated that the steam used for the jets did not exceed 3 per cent. of that generated. He emphasised the fact that the heat generated by coke is chiefly utilised as radiant heat in the boiler, and that, for this reason, the fire-box heating surface was the chief factor in steam production.

The tendency on American railways, where coke-breeze, mechanically stoked, was being employed for steaming purposes was, he stated, to increase the area of the fire-box heating surface, and to diminish that of the tubes. Reliable tests had proved that 1 square foot of fire-box heating surface, when exposed to direct radiation from burning coke, will evaporate five times as much water as 1 square foot of tube surface. Stationary boiler designers would do well to note this fact.

IV.—*German Tests with Coke and Coke-breeze.*—In the year 1910 a Commission was appointed by one of the leading German Societies of Mining Engineers to investigate the utilisation of low-grade fuels, and the reports issued by this Commission have been published from time to time in the German mining journal, *Gluckauf.* Some of the figures and results obtained by this Commission with coke and coke-breeze will now be quoted :—

Two evaporative tests were carried out on August 2nd and 3rd, 1910, with the "Praesto" and "Kridlo" systems of firing, at the Consolidation Mine, near Dortmund, with coke-breeze or ashes from the quenching plate, containing 24 per cent. ash, 15 per cent. moisture, and 4·5 per cent. volatile matter. The boiler with which this test was made was one of a battery of six Alban type of water-tube boilers, with a grate surface of 3 square metres (32 square feet), and a heating surface of 129·6 square metres (1,393 square feet). The fuel used cost at the mine only 1*s.* 8*d.* per ton. Each test lasted eight hours, and after deducting the steam used for the steam jets, the tests proved that the evaporation per lb. of fuel had been 3·03 lbs. in one case and 3·3 lbs. in the other. These results show, on comparison with those obtained with a similar fuel burned under the same conditions under a Lancashire boiler, that the water-tube type of boiler is not so suitable as the other for use with a fuel so low in volatile matter, and confirm what was said on this subject in the introduction.

Further tests made with a similar fuel, and the same systems of firing, were made on August 25th, 26th, and 31st, 1910, on one of the installation of ten Lancashire boilers at the Ludwig Mine, Westphalia. The coke-breeze in this case contained 10 per cent. volatile matter. The grate area was 2·96 square metres (31 square feet), the heating surface was 93·4 square metres (1,003 square feet), and the forced draught was obtained from an electrically-driven fan, which supplied air under pressure to the ashpit of each boiler furnace. The results of three tests showed that 5·2 lbs., 4·90 lbs., and 4·64 lbs. respectively of water had been evaporated per lb. of fuel burnt, and that the cost of evaporating, after allowing for all running and fixed charges, had been from 3*s*. 3*d*. to 3*s*. 5*d*., or a mean of 3*s*. 4*d*. per 1,000 gallons of water.

Some figures obtained by the same Commission at the Achenbach Mine, with coke and coke-breeze, burned by aid of the Wilton apparatus for producing forced draught, will now be given :—Three steam jets were used to force the air into the furnace, and a special form of distributing box was employed to carry the air up through the furnace bars into the bed of burning fuel. The steam jets were not employed continuously, but were closed for about one-fourth of the time when the fires were being cleaned, or fresh fuel was being charged. A separate test was made of the steam required to produce the blast, by allowing a similar steam jet to blow through a cooling worm, and by weighing the water condensed. This amounted to 74·3 kilos. per hour for the first test, and to 86·5 kilos. per hour for the second test, and represented about 3 per cent. of the steam production of the boiler. Comparative tests were made in September and November, 1912, with the natural draught and forced draught systems, and the following are the more important average figures obtained in the four trials, the test in each case lasting eight hours :—

	Natural draught.	Forced draught.
Cost of fuel per ton	1*s*. 7*d*.	1*s*. 7*d*.
Water evaporated per lb. of fuel . . .	4·08 lbs.	4·99 lbs.
Water evaporated per square foot of grate area per hour	20·50 lbs.	36·70 lbs.
Cost of evaporating 1,000 gallons of water .	3*s*. 8*d*.	3*s*. 1½*d*.
Boiler efficiency	52·4 p.c.	65·8 p.c.

The special feature of these German tests is the low charge for the fuel used, and, consequently, the very economical figure for the cost of evaporating 1,000 gallons of water, namely, 3*s*. 1½*d*. to 3*s*. 8*d*., as compared with 7*s*. 9*d*., the lowest cost for the English returns. When comparing the figures, however, we must note that the German tests were made at the mines or coke ovens, with fuel which would have otherwise been wasted, and that the charge made for it to the boilers was merely a nominal one. With coke-breeze at the same cost, the English figures for the cost of evaporating 1,000 gallons of water would prove equally striking.

GASIFICATION.

As regards the use of coke-breeze in the types of producer specially designed for the gasification of finely divided fuels (referred to in Chapter I), the following are tests of the gas obtained from a coke-breeze containing 40 per cent. dust, when used in the Kerpely high-pressure producer, the calorific value of the breeze being 10,250 B.Th.U. :—

Carbon-monoxide,	27·5 per cent.	Hydrogen,	8·5 per cent.
Carbon-dioxide,	3·4 ,,	Methane,	·10 ,,

The net calorific value of the gas was 118 B.Th.U. per cubic foot, and it was employed for heating the gas retorts at the Vienna Gas Works.

The following are test-figures obtained with the Tees producer, when running on coke-breeze of the grade and chemical composition specified in the test :—

GRADING OF FUEL.	PER CENT.
Over ½ inch	27·6
½ inch to ¼ inch	33·1
¼ inch to ⅛ inch	19·3
Below ⅛ inch	20·0

ANALYSIS OF FUEL.	PER CENT.	
Moisture	14·29	
Ash	22·33	on dry sample.
Volatile matter	5·1	
Total carbon	74·45	
Calorific value	11,109 B.Th.U.'s per lb.	

Blast pressure at bars . . = 18 cms. (7·0 inches).
Gas pressure at top of producer . = 5 cms. (1·9 inches).
Blast saturation . . . = 63° C.
Temperature of gas leaving producer . . . . = 197·5° C.
Analysis of gas . . CO_2 = 6·4 per cent.; CO = 25 per cent.; H = 14 per cent.
Net calorific value . . . = 124 B.Th.U.'s per cubic foot.
Gas per ton of wet breeze . . = 110,000 cubic feet.
Ash . . . 87·3 per cent. incombustible; 10·73 per cent. carbon.
Gross efficiency (calculated) . 67·7 per cent.
Net efficiency (calculated) . . 65·2 per cent.

Fig. 21 is a sectional elevation of this gas producer.

Finally, figures given by Fernald in Technical Paper, No. 123, published by the U.S.A. Bureau of Mines, may be quoted. The gas producers in this case were fed with coke "ballast," which is another name for the "fines" obtained when screening coke, and the gas was employed for firing brick-kilns. The producers were of the non-recovery type with stationary grates, and for several years the work of the kilns had been carried on quite successfully with the gas obtained from this coke-ballast.

No details of the calorific value of the gas are given, but the grading and analysis of the fuel used was as follows :—

GRADING OF FUEL.	PER CENT.
Over ½ inch	40
½ inch to ¼ inch	19
¼ inch to ⅛ inch	14
Below ⅛ inch	27
	100

ANALYSIS OF FUEL.	PER CENT.
Moisture	10·77
Ash	12·05
Volatile matter	4·92
Fixed carbon	72·26
Calorific value	11,160 B.Th.U.

In concluding this chapter on the use of coke and coke-breeze for steam-raising purposes, reference may be made to the fact that the two most favourable openings for the utilisation of coke are on railways and in factories for power purposes, and it is significant that both in Germany and America the use of coke and coke-breeze in both of these directions is extending very rapidly.

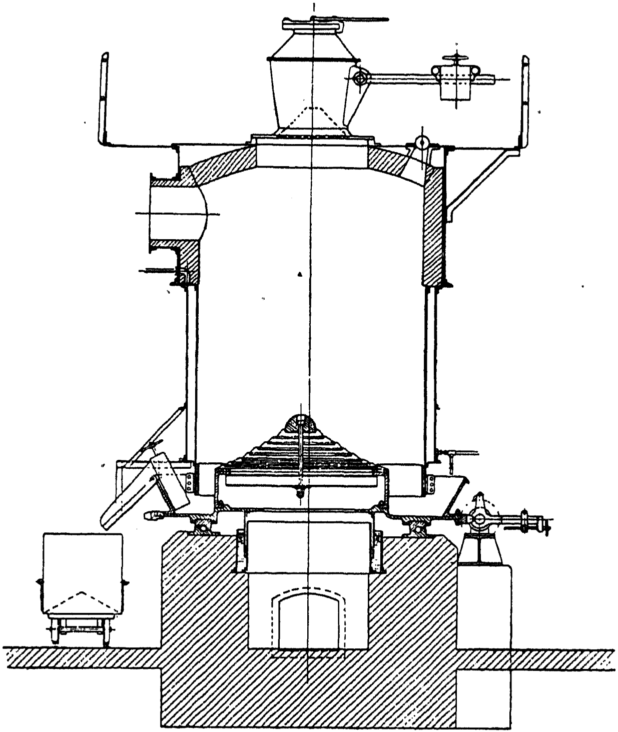


FIG. 21.—The Tees Gas Producer.

CHAPTER V

CULM AND WASHERY WASTE

One unlooked-for result of the increased cost of labour and transport in all manufacturing countries is that the " dumps " of waste fuel in colliery districts are growing in size, and that the proportion of fuel left in the mines as unmarketable and not worth bringing to the surface is far greater than is desirable from the point of view of national economy.

Large consumers of fuel, in towns and cities far distant from the coal-mining areas, have, in fact, now recognised the absurdity of paying high freight and railway charges upon such incombustible matter as shale and dirt; consequently, washed and properly graded coals are rapidly growing in favour. The large shipping companies also have commenced to use washed hard fuels from the South Yorkshire coal-mining area, in place of South Wales steam coal, and the demand for scientifically prepared fuels is thus increasing, month by month and year by year. The coal-washing and cleaning plants at collieries, therefore, tend to multiply in all up-to-date mining centres, and the dumps of culm and other washery refuse are growing in size, and also in economic value.

So far the attempts to utilise this waste material for steam raising or other power purposes have been confined chiefly to the colliery companies themselves, but with the extension of their plants the time is rapidly approaching when the companies will be unable to burn or gasify even a small proportion of their total output of this low-grade fuel, and its sale to outside consumers will become necessary.

Owing to the high percentage of incombustible matter, it will not pay to transport the material far from the mining centres where it is produced, but within a certain limited radius, say five to ten miles, culm and washery refuse, when burnt under steam boilers or gasified in producers, form very valuable cheap fuels for power generation.

Special types of furnace grate and of gas-producer are, however, necessary in order to obtain good results with these materials, and in the following pages some facts and figures are given, based upon recent practical trials in England, America, and Germany.

THE UNITED KINGDOM.

The early attempts to utilise culm and washery waste for steam raising in the United Kingdom were made in furnaces of the destructor type, for it was recognised that it would be impossible to obtain a good evaporative efficiency from fuels containing from 25 to 35 per cent. of ash, in the ordinary type of boiler furnace.

Goodrich, in the *Engineering Magazine*, some years ago, pointed out that a Lancashire boiler with a grate area of only 38 square feet could not possibly maintain its proper rate of efficiency with a fuel the evaporative power of which was at the best only 4 lbs. of water per lb. of fuel, and he proposed that the grate area should be doubled, and that compressed air should be employed to support the combustion. External brick cells with grate areas of from 50 to 75 square feet were therefore provided, and under these conditions, with forced draught, an evaporation of 10,000 lbs. of water per hour, with a Lancashire boiler measuring 30 feet by 8 feet, became possible. This Dutch oven type of furnace, however, while quite useful for large-sized material and the " brasses " from hand-picked coal, was found to be impracticable when fine-grained material and the refuse from washeries had to be burned, and the Bettington type of tubular boiler has now come to the front as one of the most suitable for steam raising purposes with these classes of low-grade fuel.

The Bettington boiler is illustrated in Fig. 22, which gives a sectional elevation and cross-section of it, on the line A.B. of the larger figure. The fuel, which must be sufficiently dry

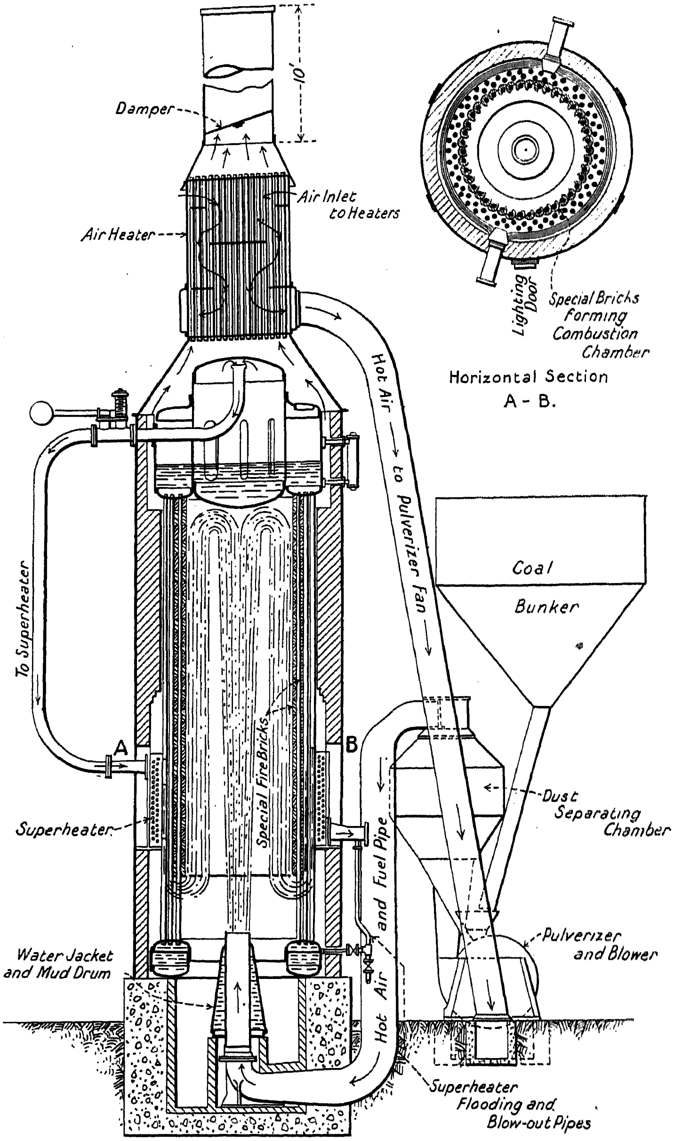


FIG. 22.—The Bettington Boiler for Dust Firing.

to be picked up and carried forward into the combustion chamber of the boiler by the jet of preheated air from the blower, is first carried vertically upwards by the force of the blast—and in theory, the particles of carbonaceous matter should be all consumed before the gases are reversed in direction and leave the lower part of the combustion chamber by the path shown in the figure.

Professor Cobb, in a paper read in April, 1916, before the Midland Section of the Coke-Oven Manufacturers' Association, has pointed out that the Bettington boiler will require modification in some respects before it can completely burn large-sized grains of coal. The time during which the particles remain in the combustion zone of the boiler with the present design, is far too short to allow of their complete combustion. The question of the best materials for the refractory lining of the boiler is also not yet settled, for the high temperature and the molten ash or slag combined have a most destructive action upon it. However, these difficulties will, no doubt, be overcome in time, and when they are, the Bettington boiler will prove a very efficient type of steam producer, when fired with the finely divided waste materials from coal cleaning plants and washeries. The coal dust that accumulates upon the floors and ledges of mines, and proves such an added danger when explosions occur, could also be collected and utilised for steam production if a battery of Bettington boilers were installed at or near the pithead in all coal-mining districts.

The evaporative capacity of these boilers is high, and it is stated that a Bettington boiler with 2,600 square feet of heating surface, under the best working conditions, will evaporate 22,000 lbs. of water per hour, and show a thermal efficiency of 75 per cent. The latest published tests with this boiler were carried out at the works of the Farnley Iron Co., Yorkshire, and the results are recorded in a paper read by C. A. King before the Yorkshire section of the Society of Chemical Industry, in January, 1917.

The following are the chief figures obtained, (1) when the boiler was running under normal conditions, and (2) when operating under 30 per cent. overload :—

Normal load (12,000 lbs. per hour, from and at 100° C.).

TEST I.

	In Five Hours.	Per Hour.	Per lb. Coal.
Coal	65 cwts.	1,344 lbs.	—
Water from 44° C. to 160 lbs. and 108·6° C. superheat	5,345 galls.	9,718 lbs.	7·23 lbs.
Water from and at 100° C.	—	12,300 lbs.	9·15 lbs.
Boiler efficiency = 76·9 p.c.			

TEST II.—30 PER CENT. OVERLOAD.

	In Two Hours.	Per Hour.	Per lb. Coal.
Coal	31 cwts.	1,736 lbs.	—
Water from 72·8° C. to 160 lbs. and 111·8° C. superheat	2,712 galls.	13,560 lbs.	7·81 lbs.
Water from and at 100° C.	—	16,544 lbs.	9·53 lbs.
Boiler efficiency = 80·0 p.c.			

DISTRIBUTION OF HEAT.

	Normal.		Overload.	
	Per cent.		Per cent.	
Retained by boiler alone	68·3	76·9	69·1	80·0
Retained by superheater	6·8		9·1	
Retained by air heater	1·8		1·8	
Loss in flue gases	16·8	23·1	17·9	20·0
Loss by radiation	6·3		2·1	

As regards the use of waste fuels for producer work in the United Kingdom, Fernald, in Technical Paper No. 123 of the Bureau of Mines, gives some figures obtained from the manager of a large English colliery and ironworks. In the particular case referred to, a water-jacketed revolving grate producer was installed for the purpose of utilising the "batts" from the colliery dumps of waste fuel, "batts" being the local term for the larger pieces of shale containing a good proportion of coal. It has been found in practice that better results can be obtained by crushing the larger material, and by passing both the large and small through a washing plant before charging into the producer. In this way the dump is being gradually reduced in size at this colliery, and 115 tons of the unwashed material yield 60 tons of nuts—classified as Nos. 1, 2 and 3—and 40 tons of slack. The sample of the original waste fuel taken from the dump tested as follows :—Moisture, 6·99 per cent. ; ash, 52·12 per cent. ; volatile matter, 18·37 per cent. ; fixed carbon, 22·52 per cent., and the calorific value of the undried fuel was 5,065 B.Th.U. After washing, the fuel tested as follows :—Moisture, 5·86 per cent. ; ash, 24·60 per cent. ; volatile matter, 28·75 per cent. ; fixed carbon, 40·79 per cent., and the calorific value of the undried fuel had increased to 9,869 B.Th.U. The manager stated that the producers operated well with this washed material, and that success in dealing with it was due to the water-jacket. The slag contained on the average 4 per cent. of combustible.

THE UNITED STATES.

One of the most notable installations in America for utilising the small coal and refuse from the washing plant attached to a large colliery is that found at Hauto, Pa., and illustrated in Figs. 23 and 24. This plant was erected in 1912—1913 by the Lehigh Coal and Navigation Company, which mines chiefly anthracite coal, and the original plan was that the power station shown in Fig. 23 should be run entirely with the refuse and sludge from the washeries.

In actual practice, however, it has been found impossible to obtain the rated capacity from the boilers installed when fired with refuse alone, and therefore the smaller sizes of anthracite coal, known on the market in America as Nos. 2, 3, and 4 "buckwheat," are now being employed at the power station. These sizes of anthracite are produced by the following screens :—

No. 2 passes through $\frac{5}{16}$ inch but is retained by $\frac{3}{16}$ inch.
,, 3 ,, $\frac{3}{16}$,, ,, ,, $\frac{1}{16}$,,
,, 4 ,, $\frac{1}{16}$,, ,, ,, $\frac{1}{32}$,,

In order to reduce the costs to the lowest possible point, the coal is transported directly from the breakers and washeries to the coal bunkers of the power-house in gondola cars. The original capacity of the power plant was 30,000 kilowatts, but it is to be increased to 100,000 kilowatts, and some idea of the amount of refuse to be dealt with can be obtained from the fact that in the production of the size known as "stove coal" alone the Lehigh Company turns out enough refuse to run the whole of the enlarged plant. The original plant comprised eight Babcock and Wilcox double-ended units. Each boiler is provided with four grates, half of each set being fired from one side and half from the other. The boilers are of the five-drum bent tube type, equipped with superheaters, and are designed to carry 225 lbs. of steam pressure. Exclusive of the superheaters, each boiler has 10,000 square feet of heating surface. Six of the boilers are equipped with hand-fired dumping grates of special design, and the two remaining units are equipped with automatic travelling grates, a development of the Coxe design. In the case of the hand-fired furnaces, the grates are 12 feet deep and 8 feet wide, making the total grate area 384 square feet per boiler. Four of the boilers are provided with Acme slotted-top grates, and two are equipped with pin-hole tops. In each case about 6 per cent. of the total grate area is occupied by air apertures, the holes or slots being about $\frac{3}{32}$ inch wide. The apertures are at the bottom of grooves moulded across the grate tops, at right angles to each other, giving the appearance of a waffle-iron. The grooves are provided in order to prevent the coal from choking the apertures, and thereby hindering a free circulation of air through the furnace. Other features of the furnace are the use of vertically sliding furnace doors, recessed ashpit doors, and shaker handles to prevent obstruction to the firing aisles, double fire-arches, cinder catchers, ventilation of fire-walls

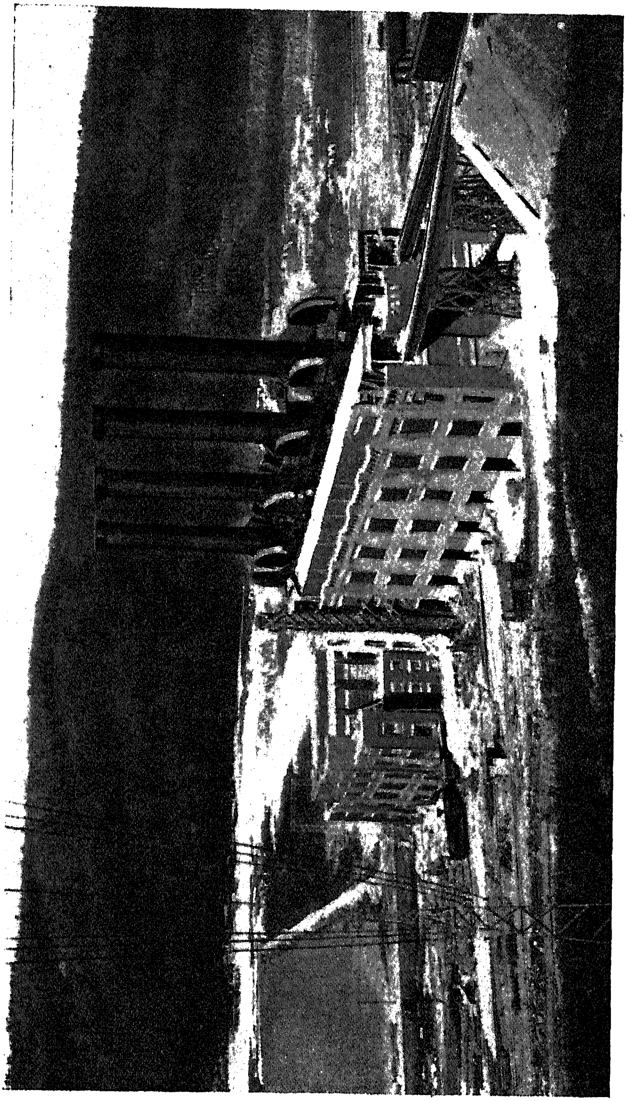


FIG. 23.—The Hauto, Pa., Electric Power Station using Anthracite Culm as Fuel (30,000 K.W.).

to prevent burn-outs, and independent brick settings which are not affected by expansion of the metal parts. Double

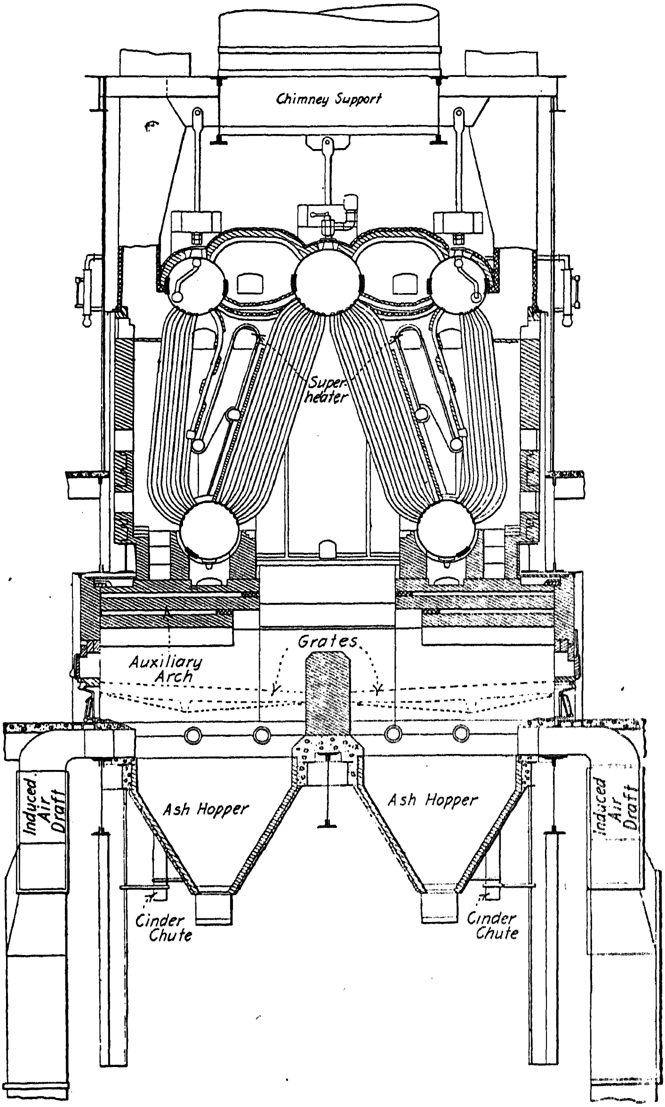


FIG. 24.—Arrangement of Boilers and Furnaces at Hauto, Pa., for burning Anthracite Culm.

superposed fire-arches are provided, so that if the lower
burns out, the upper one will come into use. Between

superposed arches is an air space through which air is allowed to circulate slowly, in order to prevent the firebrick temperature from reaching such a value that the material deteriorates. The space over the grates is practically a reverberatory furnace, which ensures the complete combustion of the fuel. The fire-arch is 9·5 feet long, and covers two-thirds of the grate area. The combustion chamber above the brick wall is unusually large, and is so designed as to reduce the velocity of the gases, and to allow any unburned fuel to drop back into the fire and to be consumed. The gases from four furnaces under each boiler pass up through the central combustion chamber and then divide at the top, going through two passes, striking the flues and superheaters—of which there are two to each boiler—and then following the vertical uptakes at the boiler heads to the roof of the station, where they join a common stack (see Fig. 24). Using No. 3 buckwheat, containing 20 per cent. ash, as fuel, the boilers can be run at 300 per cent. rating with the aid of forced draught. Whatever unburned fuel or cinder may be carried over into the first pass of the boilers is thrown out by centrifugal force at the bottom of the pass into a cinder catcher. The steam is employed to drive three turbo-generators, each of 12,500 kilowatts, generating current at 11,000 volts. The electric energy is transmitted at 110,000 volts to various coal mines and cement mills in the vicinity of the Hauto supply station.

The Lehigh Company has sold this generating station to the Electric Bond and Share Company, which is consolidating the interests and linking up all the power companies in the same area. It is probable that the extension of the plant to the size originally planned will be carried out at an early date, and that two more similar generating stations will be erected close to the mines in order to obtain the advantage of unlimited supplies of this cheap waste anthracite fuel.

Another example of an American electric power station which is using waste fuel for steam generation is provided by the plant of the Cadogan Mine in Armstrong County, Pa. The fuel in this case consists of 50 to 75 per cent. refuse from the tipple picking tables, mixed with slack. The generators are Heinz water-tube boilers rated at 470 H.P., at 150 lbs. working pressure, each having a grate area of 84 square feet. Each boiler is fed by three mechanically-operated underfeed stokers, forced draught being supplied by one blower fan driven by two direct-coupled steam engines (see Fig. 25). The ash is removed by steel cars running on rails directly below the discharging holes of the retorts. The generating plant consists of two 375-kilowatt alternators coupled direct to Corliss valve steam engines running at 150 revolutions per minute. The engines consume 21·6 lbs. per H.P. hour at full load, 21·3 lbs. at three-quarter load, and 21·8 lbs. at half load. The energy developed is used chiefly for cutting, haulage and pumping purposes at the mine, but as transmission is an important point, it is generated at 2,300 volts, and is converted by motor generator sets to direct current at 250 volts, at the point where it is required.

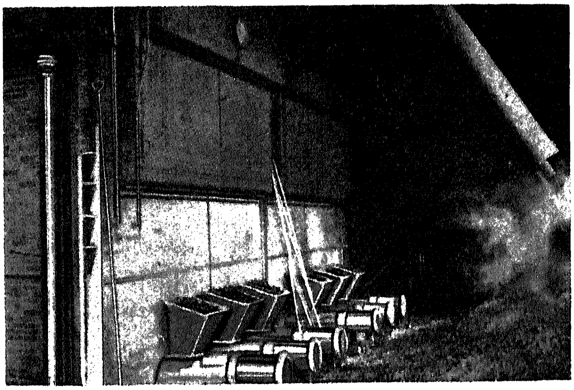


FIG. 25.—The Boilers at the Waste Fuel Power Plant, Cadogan Mine, U.S.A.

Another American power plant which utilises anthracite culm or slush as fuel may be briefly referred to. This material, it may be explained, is the fine coal that passes through a screen with $\frac{3}{32}$-inch circular holes, and in the modern coal washery plant it is the only form of anthracite for which the producers are unable to find a market. Fig. 26

shows the general appearance of the culm, with a 6-inch rule laid against it.

The Delaware, Lackawanna and Western Railroad Company, however, are burning this material with success at their Nanticoke Power Station, using Coxe chain-grate stokers and forced draught, with Babcock and Wilcox boilers working at 155 lbs. steam-pressure.

The "fingers" of these stokers are of special design and contain openings $\frac{1}{16}$ inch wide and $\frac{3}{32}$ inch in length, about 6 per cent. of the whole grate surface being taken up by these. The slush or culm is carried to a depth of 4 inches on the stokers, and a draught equal to $1\frac{1}{2}$ inches to 2 inches water is required to burn it satisfactorily. The generating plant at the Nanticoke Power Station comprises ten 300 H.P. boilers, with two sets of Allis Chalmers turbo-generators, running at 1,800 revolutions per minute, and generating three-phase current at 4,100 volts.

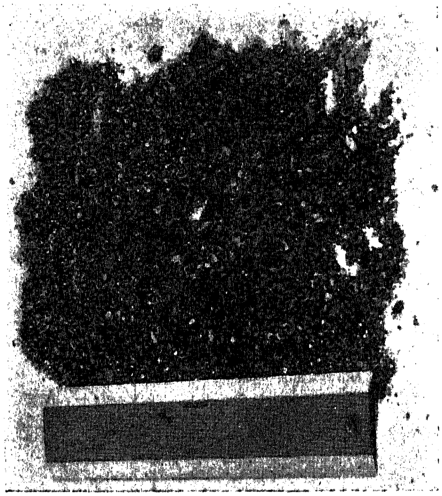


FIG. 26.—Anthracite Silt or Culm, exact size of.

Four more boilers are being installed, and further details of the plant will be found in the issue of *Coal Age* for June 8th, 1918.

Finally, a series of test figures obtained with a 750 H.P. *Maxim* boiler, equipped with a *Coxe* travelling grate, when burning the various grades of anthracite buckwheat fuel, and silt or culm, may be given. These results summarise much of the data contained in recent American contributions on the subject. The figures are taken from a paper contributed by W. P. Frey, fuel engineer of the Lelington Coal and Navigation Company, to the Spring (1918) Meeting of the American Society of Mechanical Engineers, when the subject of the *Utilisation of Fine Grades of Anthracite* was under discussion :—

	No. 1 Buck-wheat.	No. 2 Buck-wheat.	No. 3 Buck-wheat.	No. 4 Buck-wheat.	Un-cleaned silt.
Average H.P. of test .	1,500	1,395	1,200	1,010	495
Maximum H.P. of test .	1,750	1,600	1,400	1,100	650
Average per cent. rating.	200	186	160	134	66
B.Th.U. per lb. dry coal.	12,250	12,000	11,500	11,000	10,000
Combined efficiency of boiler, furnace and grate . . .	74	70	65	61	45
Equivalent evaporation from and at 212° F., per lb. of dry coal .	9·35	8·77	7·7	6·9	4·6
Dry coal consumed per H.P. hour . . .	3·69	3·93	4·48	5·00	7·5
Dry coal per square foot grate surface per hour	25	25	25	25	25
Boiler H.P. per square foot grate surface .	6·8	6·36	5·5	4·9	3·3
Grate travel in feet per hour . . .	16·6	16·5	16·2	15·2	11·1

The general conclusions that may be drawn from American experience and practice with these low-grade fuels are two. First, it is recognised that some form of artificial draught is requisite for the proper combustion of the smaller sizes of waste fuel, forced fan draught operated on the " balanced draught " principle being most favoured. Secondly, it has been proved that only in exceptional cases will it pay to grind or pulverise the lump waste fuel, in order to burn it in dust form. When the fuel is brought to the surface in this finely divided state, this method of burning is the most efficient, but in nearly all cases the fuel is too poor to pay for the cost of artificial pulverisation. The heat produced by burning rich " culm " in the dust form is sufficient to melt all forms of refractory material, but this is an exceptional material, and the greater number of waste fuels contain so large a proportion of ash that when burnt in the dust form the temperature produced is not so high as that attained under ordinary conditions with lump fuel.

GERMANY.

Experimental trials were carried out by Butow and Dobblestein in 1910—1911 for the Westphalian Mine-Owners' Association in connection with the utilisation of waste fuels at the mines, and a summary of the results obtained and conclusions arrived at has been published from time to time in the German mining paper *Gluckauf*. Butow and Dobblestein state that low-grade fuels may be classified according to their origin as follows :—(1) Coarse-grained material with ash contents up to 50 per cent. and water up to 20 per cent. (2) Fine-grained material with ash contents up to 40 per cent. and water up to 30 per cent. (3) Small coke and coke-breeze with ash contents up to 30 per cent. and water up to 20 per cent. Two methods of utilisation for these low-grade fuels are open to the engineer : they may be burned under steam boilers either alone or in conjunction with other materials, or they may be gasified in producers. Fuels of class (1), they assert, can be burned directly without admixture with other material, but the steam-raising efficiency of the boiler is very low, and such fuels can only be employed in large boiler installations. The application of forced draught gives very little advantage in the case of these fuels, and their utilisation directly for steam-raising purposes is therefore restricted to special cases. Fuels of classes (2) and (3), when they can be obtained, yield the best results when fired together, this being specially the case with the fine coal from a rich or gas coal, and coke-breeze, which together yield an excellent firing material for steam boilers. In this case the use of forced draught increases the efficiency of the firing. As regards fuels of class (3), Butow and Dobblestein state that these can be fired alone if they contain 10 per cent. of volatile matter, and if forced draught is available. Coke-breeze containing less than 10 per cent. of volatile matter cannot be fired alone, and if no fine material from a rich or gas coal is available for mixture, it must be briquetted with the aid of pitch. Should the ash and water contents of the breeze exceed 30 per cent. it will not pay, however, to briquette it, and for this material, as for the lowest grades of classes (1) and (2), gasification in producers is the only practicable method of utilisation.

In a later report, the same two engineers give details of steam-raising tests made in July, 1911, at the "Prosper" Mine, with low-grade fuels and a travelling-grate stoker. Fuels containing from 9 up to 22 per cent. ash and from 2 up to 13 per cent. water were used in these tests. The fine coal from the coal-washing plant and the coke ashes could in neither case be burned alone, and were, in the final tests, either burned together or mixed with the other fuels. A Dürr boiler possessing a heating surface of 1,640 square feet was employed in the trials. Six tests were made with the following products :—(1) Rejected fuel from the washing plant. (2) No. 1 fuel mixed with coke ashes in the proportion of 2 to 1. (3) Dust from nut coal mixed with coke ashes in the proportion of 3 to 1. (4) A mixture of two parts of fine coal dust with one part of coke ashes. (5) A mixture of equal parts of fine coal dust and rejected fuel from the washer. (6) Dust from nut coal alone. The following results were obtained :—Pounds of steam obtained per lb. of fuel burned : (1) 5·61, (2) 4·96, (3) 4·16, (5) 4·45, (6) 5·55. Boiler efficiencies : (1) 58·96, (2) 53·18, (3) 42·93, (5) 48·74, (6) 55·95. The cost of one ton of steam, using the rejected fuel from the washing plant, was only 9*d*., of which total the fuel represented 6*d*.

As regards the use of these waste fuels for gasification, Butow and Dobblestein state that the chief difficulty met with has been the bulk of the slag and ashes which has to be removed from the producer, and the tendency of this to fuse together into large masses, and to disturb the normal working of the producer. The producers experimented with were—(1) the Mond producer, and (2) the Erhardt and Schmer producer. Coke ashes containing 19·4 per cent. ash and 20·7 per cent. moisture were used. The trial of the Mond producer with this fuel failed, owing to the air pressure required to burn it being sufficiently great to blow out the water seal. So far as could be judged from the preliminary results of the test, 1 cubic metre (35 cubic feet) of gas, testing 112 B.Th.U. per cubic foot, would cost ·0235*d.* (·20 pfg.), without any allowance for labour, depreciation or interest charges.

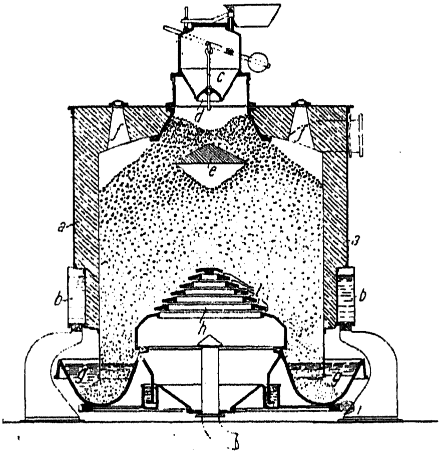


Fig. 27.—Augsburg-Nürnberg type of Gas Generator.

The trials with the Erhardt and Schmer generator were more successful, as this producer possesses a rotary hearth which retained all the fuel in the lower part of the charge in continual motion, and thus prevented clinker formation. In this case, a mixture of equal proportions of coke ashes and refuse from the washing and sorting machines at the mine was used, and after the method of burning the generated gas under a Lancashire boiler had been modified, very successful results were attained. The following is an estimate of the cost of evaporating 2,204 lbs. of water with this cheap fuel refuse :—

	Pence.
Labour	4·8
Interest and depreciation	4·8
Fuel	3·0
Feed-water	·6
Power for motor	·8
Total	14·0

For a larger plant this low cost could be still further reduced, as the same labour would suffice for two producers, and 2,204 lbs. of water could then be evaporated for 12*d.* By use of the gas in a gas-engine, still more favourable results could be attained.

Finally, a report made by Mann and Mustefeld upon the gasification of low-grade fuels, and published in *Gluckauf* in 1912, may be referred to. These authors state that the chief characteristic which determines whether a fuel is to be classed as "low grade" is the fineness of its particles ; ash and moisture are of secondary importance. The chief factors that determine whether any particular low-grade fuel will pay for its gasification are :—(1) The chemical composition of the gas that can be produced from it, and (2) the cost of obtaining one calorie, or heat unit, in the gas produced. The chief difficulty in working gas-producers with these low-grade fuels is due to the finely divided state of the particles. This causes great resistance to the air supply inside the producer, incomplete combustion occurs in consequence, and the yield of gas is diminished. Air channels are also formed in the burning mass of fuel and lead to further disturbances of the normal conditions of work, since they carry an excessive air current, which results in the formation of CO_2 in place of CO.

The authors give details of trials made with the Mond, Erhardt and Schmer, Maschinen Fabrik Augsburg and with the Kerpely producers (see Figs. 27 and 28), when using this class of fuel. The steam required to operate the different types of generators varies from 15 to 18 lbs. per 100 lbs. of fuel in the case of the Kerpely producer up to 200 lbs. in the case of the Mond producer. The Kerpely high-pressure producer is described in the form specially designed for gasifying finely divided low-grade fuels. A satisfactory gas composition is obtained from these producers by the use of a great depth of fuel bed and by a uniform distribution of the air supply over the whole area of the combustion zone. The ashes and clinker are continuously abstracted as the gasification of the fuel proceeds. The following tests show

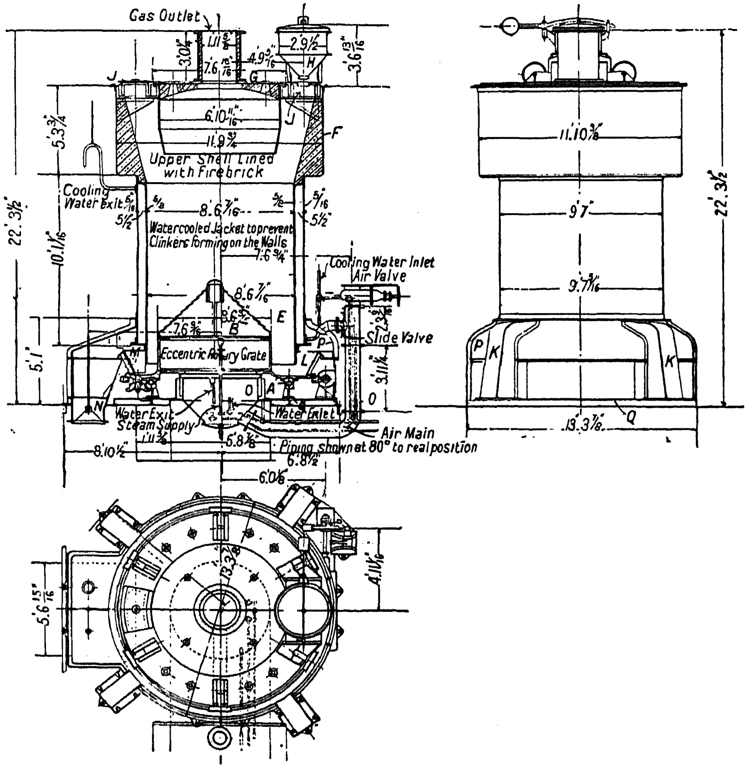


FIG. 28. Kerpely type Revolving Grate Gas Producer.

the chemical composition of the gas made in a Kerpely producer during six separate trial runs :—

	1.	2.	3.	4.	5.	6.
CO_2 . . .	3·00	5·18	10·0	7·0	2·4	4·1
CO . . .	30·20	26·66	21·9	27·4	32·5	29·5
H	14·85	15·01	22·2	18·3	12·3	14·5
CH_4 . . .	·40	1·90	2·0	2·5	—	1·4

CHAPTER VI

TOWNS' REFUSE AND GARBAGE

ANOTHER of the waste materials that may be utilised as substitutes for ordinary fuel for power generation is towns' refuse, since not only is its quantity large, but its destruction by burning is imperative in all large towns and crowded centres of population. Further, the heat produced by its combustion is most easily utilised by means of steam boilers and electrical generators, and the slag produced by its combustion may also prove a valuable source of revenue.

The earliest forms of refuse destructor were simply designed for the combustion of the refuse without utilisation of the hot gases for steam generation, and the destructor consisted essentially of a square or oblong brick-lined chamber or cell (*i.e.*, a Dutch oven) of large dimensions, into which the refuse was tipped and burned under natural draught, generally with the aid of added coal or some external source of heat.

It was soon discovered, however, that by use of forced draught and a pre-heated air supply the refuse could be burned by the aid of the heat generated from the combustible matter already present in it when collected from the streets and from the dust-bins of business and private premises—and that the heat of the escaping gases could be used successfully to raise steam in specially designed boilers.

In the following pages the author will discuss :—

I. The calorific value of towns' refuse.
II. The recent improvements in the design and in the control of the destructor process.
III. The practical industrial value of the heat generated from towns' refuse.

I. The Calorific Value of Towns' Refuse.

It may be candidly admitted that many of the published figures relating to the calorific value of towns' refuse are unreliable and misleading, and that some of the earlier estimates of the number of kilowatts that might be produced from a ton of refuse were much too high, and have only been approached in specially situated districts where the calorific value of the refuse is unusually good.

Towns' refuse is a product that varies greatly in composition and value, not only in different towns, but also in the different districts of the same town, and at different periods of the year. The only figures that are reliable as to its calorific value therefore are those based upon twelve months' operation of the destructor plant, since the summer value of the refuse is generally lower than the winter.

In colliery districts where the miners' families obtain their coal for nothing, or at a nominal price, and the general public pay only about one-half of the price charged to the consumers in large towns, the fuel value of the refuse will also be twice as high, owing to the presence of much unburned carbon in the cinders. In towns and cities far from a coal-mining district, on the other hand, the refuse will be found to consist largely of kitchen and garden garbage which, if wet, has little value for steam-raising purposes.

Bearing these facts in mind, one can now proceed to examine and analyse the figures obtained in tests of the more recently erected destructor plants, with a view to ascertaining the real fuel value of the refuse collected from a town of average size. The figures presented are mostly those obtained during test-runs of the plant when taken over from the engineering firm which designed and erected it, and a standing deduction of 33·3 per cent. will be made from these figures, in order to bring them into line with the results that may be expected from twelve months' practical operation of the plant. This percentage deduction has been arrived at by study of the comparative data published in the early years of destructor development for short test-runs, and for one year's operation of combined destructor and electric generating plant.

The Horsfall Destructor.—The New Destructor Company which now controls the Horsfall system of refuse destruction have given, in a recent publication, a tabular statement showing the gradual improvement in the efficiency of their destructors during the period 1900—1910. The results are based on tests of not less than twenty-four hours' duration, and the water evaporated per pound of refuse shows an increase from 1·21 lb. for the destructor erected at the Pembroke Electricity Works, Dublin, to 1·57 lb. for the Poplar Electricity Works, in 1910. The details of this last test are as follows:—

Date of test	February-March, 1910.
Tons of refuse burned per twenty-four hours.	153 tons.
Evaporation per lb. of refuse from and at 212° F.	1·57 lbs.

The Heenan & Froude Destructor.—The following results of tests with the Heenan & Froude type of refuse destructor are of special interest, since they emphasise the great variation in the thermal value of the refuse in different parts of the country, and illustrate the remarks made above on the point. (See next page for this Table.)

Foreign Types of Destructor.—The first destructor erected in Germany was that at Hamburg in 1895, a result of the cholera epidemic in the previous year. This was of the Horsfall type, and some trouble due to the use of steam jets was experienced before it worked satisfactorily. Brussels followed the example of Hamburg in 1903, and Zürich in 1904, by erecting similar destructor plants. These were also of the Horsfall type. The first German designed destructors were those erected at Wiesbaden by Dörr, and at Kiel by Herbertz, in 1905—1906. These designers made use of the principle of using hollow chambers in the walls of the destructor cell for the purpose of heating the incoming air, which was forced by fans into the combustion chamber under a pressure of 400 mm. (16 inches) water.

TABLE I.—TESTS WITH HEENAN & FROUDE DESTRUCTOR.

Town.	Date of test.	Period of test.	Pounds of water evaporated per pound of refuse.
Aberdare (South Wales)	March 24th, 1915.	10 hours	3·53
Pontypridd (South Wales)	Feb. 10th, 1910	8 ,,	2·69
Coventry	April, 1911	48 ,,	2·00
Rotherham	Jan. 27th, 1910	18 ,,	1·80
Clydebank	May 2nd, 1907	8½ ,,	1·73
West Bromwich	—	8½ ,,	1·45
Swinton	Sept. 24th, 1912	11 ,,	1·32
Cheltenham	June 26th, 1908	17½ ,,	1·24
Rotterdam	Feb. & May, 1913.	6 days	1·10
Rotterdam	Feb. & May, 1913.	10 ,,	·88

N.B.—These are actual evaporations, and are not expressed on the standard basis "from and at 212° F."

As might be expected from the methods of domestic heating in use in Germany—by closed stoves using chiefly briquette fuel—the refuse collected in German towns and cities was less rich in combustible material than English refuse. At Pucheim the evaporative efficiency was ·891 lb. of water per lb. of refuse—equivalent to 1·01 lbs. from and at 212° F.—while at Fürth—Humboldt system—the actual evaporative efficiency was ·98 lb. water per lb. refuse, equivalent to ·97 lb. from and at 212° F. The general results obtained at these two installations showed that German refuse had an average heat value of only 2,160 B.Th.U. per lb., and that about one-half of this heat value could be utilised for steam-raising purposes.

The English figures, consequently, show much higher evaporative efficiencies, the average for the Heenan and Froude type of destructor being over 1·87 lbs. water per lb. of refuse, and that for the Horsfall destructor being 1·38 lbs. Taking 33·3 per cent. off these figures we have 1·25 and ·92 lbs. respectively. It is unlikely, however, that in view of the increased price of fuel, and the urgent necessity for the practice of economy on the part of all sections of the population, that English house refuse will in future contain so much cinder and unburned carbon as in the past, and it will be wise therefore to assume that the average calorific value of towns' refuse, when calculated upon twelve months' working of the destructor, is about 2,160 B.Th.U. per lb. and that only 1 lb. of water can be evaporated per lb. of refuse burnt for steam-raising purposes. The practical application of these figures will be discussed in the final portion of this chapter.

II. Recent Improvements in Design and in Control of the Destructor Process.

The difficulties met with in the destruction of house refuse by burning are chiefly those arising from the physical character of the materials to be consumed, and the large amount of clinker produced as a result of the combustion of the refuse. Kitchen garbage and similar refuse is generally wet, and will not burn at all until dried; while the rags, waste paper and cinders, that form the other chief combustible elements of the refuse, are so distributed and buried amongst the mass of incombustible material that it is very difficult to get an adequate air supply at the points where it is most required. According to Broadbent, the average composition of London refuse is as follows:—Ash, 47 per cent.; breeze and cinder, 25·5 per cent.; paper, straw, and vegetable refuse, 13 per cent.; dust and dirt, 9·75 per cent.; while the remaining 4·75 per cent. is made up of bones and offal, rags, bottles, broken crockery, glass, and tin cans. The combustible material therefore does not amount to more than one-third of the whole, and the difficulties of burning it are much greater than those encountered in burning the poorest qualities of slack or coke-breeze containing 30 per cent. to 35 per cent. of ash.

When the combustion has been successfully effected the fused clinker that remains behind is over one-third the weight of the original charge of refuse, and special forms of grate and special appliances are necessary in order to deal with this large amount of molten matter, and to avoid heat losses by its withdrawal from the furnace.

The difficulties of attaining complete combustion have been overcome by the use of fans for supplying pre-heated air under considerable pressure, perforated iron plates being employed for the furnace sides and bottoms in many of the new types of destructor, in order to distribute this air through the whole mass of material to be burned. The air is pre-heated either by passing through the hollow wall-spaces between the different cells of the destructor, or by special air-heaters placed in the hottest part of the combustion chamber of the furnace. It is now recognised by designers of destructor cells that a pre-heated air supply is a *sine quâ non* of good destructor working, for a difference of 300° C. in the heat of the incoming air makes a difference of 350° to 400° C. in the actual temperature attained in the furnace. The advantages of a pre-heated air supply are not confined to this increase of thermal efficiency, for a quicker ignition of the refuse and an accelerated combustion accompany the

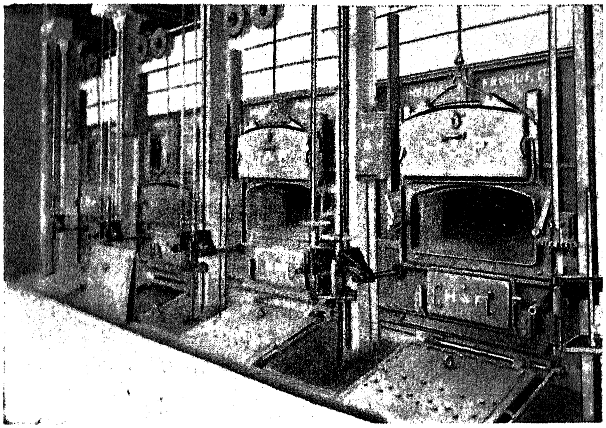


FIG. 29.—Furnace Room of Destructor Plant, New York City (Heenan & Froude).

use of hot air, and the capacity of the destructor per day of twenty-four hours is therefore greatly increased.

The high temperatures which are attained in the destructor furnaces or cells when worked with forced hot-air draught, while leading, however, to a much higher efficiency for the furnace and boiler, have created some difficulties of design, for the molten slag has been found to have a very destructive action on the furnace floor and walls, and in some cases steam-jets have been employed purposely, in place of fans, as in the Meldrum furnace, in order to keep down the furnace temperatures.

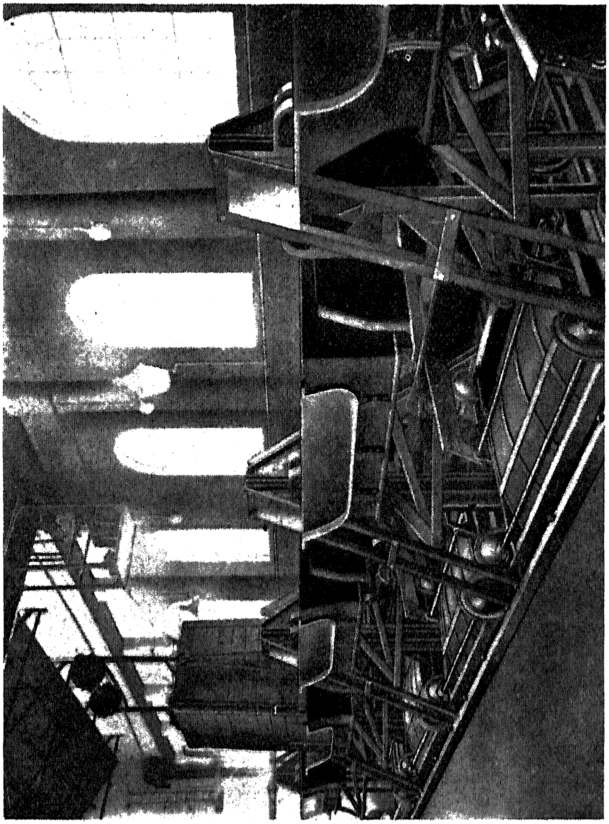


FIG. 30. Horsfall "Tub-feed" and Charging Gear at Destructor Plant, Liverpool.

Steam, however, is a wasteful constituent of gases which are to be utilised later on for heating purposes, and the best method of producing the draught required for combustion of the refuse is by fans, which draw the cold air through the hollow walls of the cells, and deliver it underneath the perforated plates which form the floor of the furnace or the inner linings of the trough-shaped grate.

A modern refuse destructor plant thus consists of the cells equipped with forced-draught fans and heat-regenerators, together with steam boilers and a dust-settling chamber, through which the gases pass before escaping into the atmosphere. In the most up-to-date plants electric power is used for charging and discharging the cells, the removal of the clinker being the most troublesome of these operations.

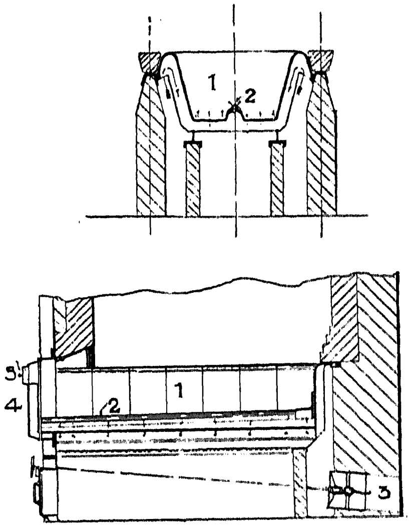


FIG. 31. Heenan & Froude Trough Grate for Refuse Destructors.

As regards the improved methods of dealing with this clinker, it has been found by actual measurements that the heat retained in the fused mass only amounts to from 3 per cent. to 4 per cent. of that generated, and attempts to utilise this heat for raising the temperature of the incoming air, or for other purposes, have not proved so successful as was hoped. The use of water-cooled mould-shaped grates which facilitate the removal of the clinker in one mass, and of a bar bent in a spiral form, around which the clinker melts, are the latest devices for dealing with the clinker problem. By means of a ring-shaped handle to the clinker bar, and a winch, a mass of fused clinker weighing several hundredweights can be removed from the furnace with ease by one man.

The Horsfall, Meldrum, Manlove & Alliott, and Heenan & Froude are the types of refuse destructor which have been most widely adopted in this country, and in U.S.A.; while in Germany and Austria, the Dörr, Herbertz and Humboldt types are found. The use of closed tubs with hopper-bottoms, for storing the refuse at the destructor plant, and of a mechanical charging gear and clinkering grate in the form of a tipping-truck, are the latest improvements in the Horsfall destructor; while Heenan & Froude have adopted a water-sealed charging device, and have also improved their method of withdrawing and quenching the clinker by use of a trough-shaped grate. In both the Horsfall and Heenan & Froude latest types of grate construction, the air for combustion is pre-heated by passing between the inner and outer linings of the trough or mould which forms the grate. Figs. 30—32 show the construction of these grates, and also the latest charging arrangements for the two types of destructor.

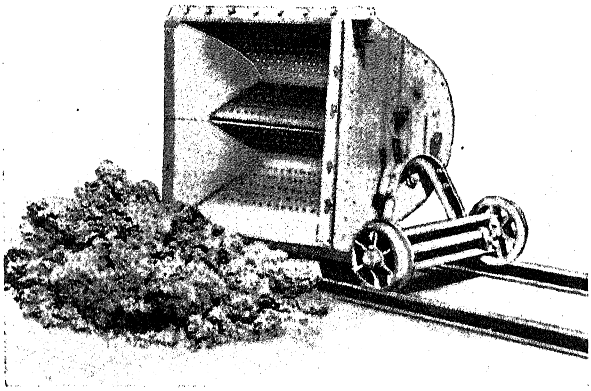


FIG. 32.—The Horsfall Tipping Trough Grate for Refuse Destructors.

The latest development of destructor design, however, is the adoption of the blast furnace as the model of what a refuse destructor should be, the Dörr destructor erected at Wiesbaden being the first of this type. Improved forms of the shaft type of destructor have been erected at Barmen and Hamburg, and as these represent a distinct departure from the ordinary type of destructor design, some details of their construction and method of working are appended.

The original Hamburg furnace was constructed in the form of an octagonal shaft, the hearth of which was rectangular in form, and water-jacketed for cooling purposes, to prevent the clinker adhering to the walls. A perforated iron grating was used for distribution of the air supply, and a fan supplied air under pressure to the air chamber below the grating. This furnace gave a mean temperature of 1,050° C. (1,922° F.), and burnt successfully 31 tons of refuse per day.

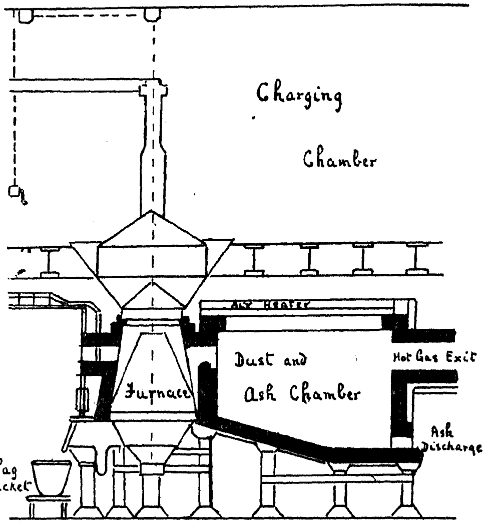


FIG. 33.—The Shaft type of Refuse Destructor at Hamburg.

An improved form of the Hamburg shaft furnace was erected later at Barmen. In this case a preliminary grate was provided in front of the grating of the shaft furnace, and on to this the clinker cake was drawn and remained twenty to forty minutes, in order that it might give up some of its heat to the incoming air. As already stated, the heat losses with the clinker are small, and the temperature of the incoming air cannot be raised to any considerable extent by contact with it.

The latest types of the shaft destructor furnace have therefore adopted special air heaters, placed in the hottest part of the system, for pre-heating the air supply, and only use the clinker heat for the preliminary step in the pre-heating process.

Kohlmann,[1] in a paper upon the "Evolution of the Refuse Destructor," read before the Canadian section of the Society

TABLE II.—TESTS OF CAPACITY FOR VARIOUS TYPES OF DESTRUCTORS.

System.	City.	Grate area, square metres.	Capacity per hour per square metre of grate surface.
Horsfall . .	Hamburg (old)	2·75	76 133 220
	Zürich . .	1·89	133
	Brussels . .	2·5	133
Heenan . .	Milwaukee .	2·5	335
	Dublin . .	2·7	260
	Cheltenham .	2·7	235
	Vancouver .	3·0	255
	Coventry .	2·7	385
Herbertz . .	Fiume . .	1·25	345
	Brünn . .	1·25	325
	Kiel . .	0·94	445
	Frankfurt .	1·1	285
	do.	2·2	480
Humboldt . .	Fürth . .	1·5	720
Dörr . .	Wiesbaden .	1·0	815
Hamburg . .	Hamburg (new)	1·2	1,530

---

[1] *Journal Society Chemical Industry*, April 30th, 1914.

of Chemical Industry, in 1913, has given the figures summarised in Table II. for the capacity of the various types of destructor.

These figures, if they are to be accepted as reliable, indicate a much higher rate of combustion in the shaft-type of furnace than for the cell-types of destructor, and this higher rate of burning would naturally lead to a reduced interest charge on capital outlay and to lower labour costs per ton of refuse dealt with. It is asserted, however, by those who are interested in the older forms of furnace, that the rate of combustion is only one of the many factors that enter into the economical working of refuse destructors, and that the claim of lower total working costs made for the shaft type of furnace has not been substantiated in actual practice. The higher air-pressure required with this type, it is said, demands much larger and more powerful fans, and the higher temperature obtained in the furnace leads to a much greater wear and tear on the refractory linings of the furnace walls and grate. The War has, of course, prevented the publication of any information or figures relating to the work of the shaft type of destructor since 1914, and it is therefore impossible to say what truth there is in these criticisms. The experience of the next two or three years will settle, no doubt, which is the more economic type for ordinary towns' refuse, namely, the subdivided cell type of furnace with a removable clinker trough as grate and moderate depth of fuel; or the shaft type of destructor with much greater depth of fuel and a temperature that approaches 2,000° F. At this temperature the clinker is only in a semi-fluid or plastic state, but no doubt with the aid of lime or suitable fluxes it could be rendered more fluid—and the advantages of obtaining a clinker from destructors that will flow readily and can be cast into moulds are so obvious, that developments are most probable along this line of progress.

III. THE PRACTICAL VALUE OF THE HEAT GENERATED FROM TOWNS' REFUSE.

The figures given in the first section of this chapter prove that house refuse has an average heat value of one-seventh that of ordinary coal, and that about 1 lb. of steam can be produced per lb. of refuse burnt. Has such a poor fuel any value at all from the power engineer's standpoint ? If this question were decided solely upon the value and merits of this refuse as a fuel, the answer to the question would be in the negative, for the interest upon the capital outlay on the destructor plant and the cost of working it would amount to more than the value of the steam produced. But, as pointed out in the introduction to this chapter, the question of refuse destruction by burning is fundamentally a sanitary one. All large towns and cities ought to be provided with destructors with sufficient capacity to cremate the whole of their refuse, and the question of utilising the surplus heat to the best advantage is really an economic one, bound up with the successful operation of these plants.

In the early days of destructor development it was customary to erect and work these plants as adjuncts of the electricity supply stations, and it was claimed that from 40 to 60 units of electricity could be obtained in these combined plants per ton of refuse burnt. The £ *s.* *d.* value of the latter as fuel was calculated therefore to be 3*s.* 4*d.* per ton.

The electrical engineers in charge of large power generating stations, however, were not in favour of the system, since a certain amount of nuisance and dust, detrimental to the efficient working of the electrical machinery, arose from the carting and tipping of the refuse ; and only a few of these combined plants have been erected in recent years.

The modern plan is to erect the destructor on the site most suitable for the collection of the refuse, to operate it as an independent works, and to sell the steam produced by the surplus heat to the nearest factory, at an agreed rate per 1,000 lbs. In some cases this sale is to an electricity supply station, but this is not an essential feature of the plan, and any large works that requires steam for heating or power purposes might cover a portion of its requirements from a destructor plant, if one were near at hand. As examples of this system of working the destructor plants at Huddersfield and at Rotterdam may be referred to.

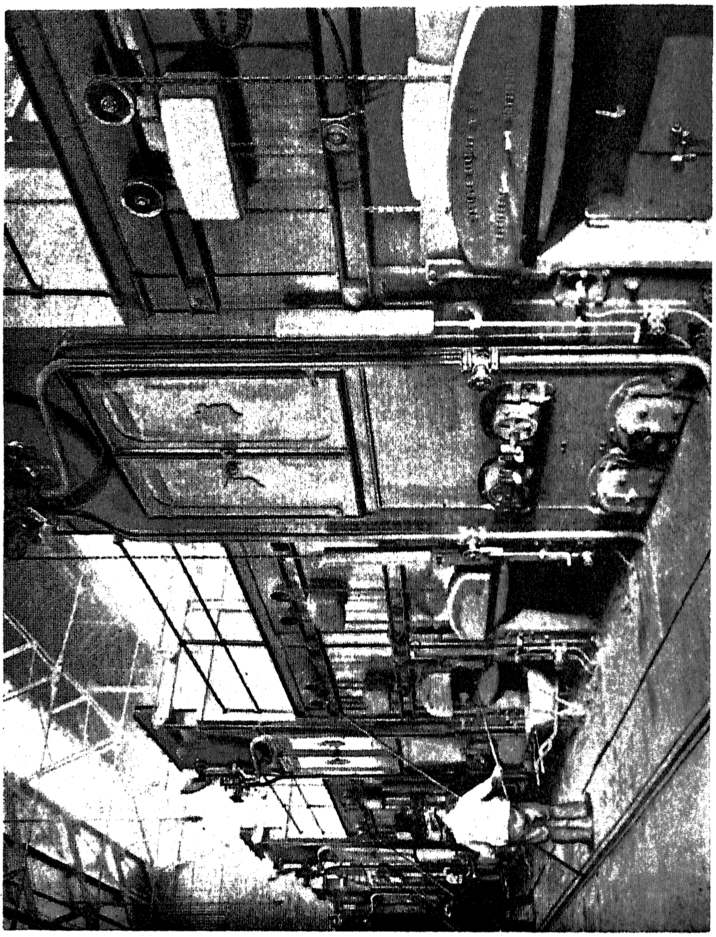


FIG. 34.—Refuse Destructor Plant at Partick (Manlove & Alliott).

The Huddersfield destructor was erected in 1910 by Manlove and Alliott, of Nottingham, and consists of eight furnaces or cells arranged in two units of four cells each, each unit being complete with its own combustion chamber and water-tube boiler. The cells are of the "back feed" type, and are arranged on the continuous system. Each cell has a grate area of 25 square feet, and is provided with a drying hearth at the rear, where the green refuse is subjected to a preliminary drying. Forced draught is provided by two electrically-driven fans, and the air is pre-heated before its entrance into the combustion chamber. The surplus steam not required for the operation of the destructor plant is carried by well-insulated steam mains over a roadway to the electricity works, and is sold to this undertaking at a net cost of 7*d.* per 1,000 lbs. The annual revenue received by the destructor plant from this source in the four years, 1911—1914, was as follows:—1911, £1,505; 1912, £1,759; 1913, £1,790; and 1914, £1,701.

The Rotterdam plant was erected in 1911, and was first put into operation in 1912. The destructors are of the well-known Heenan & Froude type, and are provided with all the improvements brought out by this firm in recent years. The plant consists of five independent units, each consisting of two sets of four cells grouped on either side of a central combustion chamber. The grates of four adjoining cells are separated from one another by low cast-iron transverse dead plates of hollow construction, so that the four grates practically form one continuous furnace chamber. Each unit is fitted with a "regenerator," consisting of a group of vertical boiler tubes expanded at the top and the bottom into horizontal tube plates. The hot gases from the boilers pass through the tubes and down into dust-pits, while the draught air passes over the outside of the tubes. The most striking feature of the installation, however, is the system of collecting the house and street refuse of the city, and of bringing it to the destructor furnaces, with a minimum of nuisance and cost. The city is divided into five districts, in each of which there is a small dock for accommodating barges. To these docks the refuse is brought in tip carts, which tip the refuse direct into skips, a number of which fit neatly into a barge. The refuse never leaves these skips until it goes into the furnaces. Each barge holds about two dozen skips, and each skip contains about 1,600 kilos. (31·5 cwt.) of refuse. The skips have bottom doors which can be opened when the device is lowered into its seating over the furnace; also they are made larger at the bottom than at the top, so that the rubbish will fall out quite readily. It is chiefly in this respect that the older systems of destructor working were faulty and capable of improvement, and although the possession of canals that ramify all through the city simplifies the collection and transport of the refuse in Rotterdam, there is no doubt that many of the good points of the Rotterdam system might be copied in other towns and cities. The official trials of the plant, made during separate runs in February and May, 1913, showed that 1,214 tons and 1,228 tons of refuse had been cremated, with an evaporation of 1·106 lbs. and ·883 lbs. of water per lb. of refuse burnt respectively; an average of 144 tons per day, and ·99 lb. steam for the whole seventeen days' period of trial. The steam raised is used partly in the plant, where the clinker is crushed and graded to three sizes, and all iron is removed by magnetic separators; while the surplus is sold to the Municipal Electricity Supply Department at a fixed rate, and is used for driving a 1,250-kilowatt turbo-generator.

The City Electricity Department provided half the capital required for the electrical portion of the plant, and for the building in which it is housed, pays the whole of the running charges of the same, and ·10*d.* per unit for the steam. Further details of this interesting plant will be found in the descriptive article from which these facts are taken.[1]

The one disadvantage of the Rotterdam system of working appears to be that there is no opportunity for sorting the refuse, and removing from it the paper, old metals and broken glass, all of which have a marketable value, especially at the present time. As an indication of the annual revenue that may be derived from this source by a destructor plant, the following figures from the 1914 report of the chief sanitary inspector of Paisley, in Scotland, are of interest :—17,576 tons of refuse, or an average of 56 tons per working day, were collected and dealt with in 1913, and 3,177 tons of clinker and 243 tons of mortar were sold. The revenue of the destructor plant from the sale of the various residual products was as follows :—

---

[1] *Electrical Times*, January 7th, 1915.

	£	*s.*	*d.*
Clinker	224	4	9
Mortar.	48	12	3
Old tins and scrap metal . . .	109	14	11
Waste paper.	15	5	8
Old bottles	4	1	4
	£419	10	11

In view of these figures, and of the fact that the relations between the sanitary and electrical departments at Huddersfield and at Rotterdam are most harmonious, it would seem probable that a considerable increase will occur in the number of destructor plants for towns' refuse, equipped with the most efficient types of furnace ; and that these plants will all derive considerable revenue from the sale of their surplus steam to the neighbouring works, and from the disposal of their clinker and other by-products to those who can make good use of these commodities. If the experience of Huddersfield and of Paisley is a safe guide, an aggregate revenue of between £2,000 and £3,000 could be obtained in all large cities from these two sources alone, and a considerable portion of the cost of destroying the refuse could thus be met.

CHAPTER VII

PITCH

In the past, pitch has been employed chiefly as a roofing, waterproofing, and paving material, for its comparatively low melting point and high percentage of volatile hydrocarbons have prevented its use on any considerable scale as a fuel, with the exception of its application as a binding agent in the manufacture of anthracite briquettes and to a lesser extent in the retorts of gasworks.

Pitch, it may be remarked here, is a product of the tar-still, and the total number of tar distillation plants in the United Kingdom in 1913, according to official figures, was 234. Under the stimulus of War conditions and the imperative need for many of the products derived from the stills, this total had increased to 356 by June 30th, 1916, and there is little doubt that, were the official figures for the expansion since that date available, it would be found that the total number of tar distillation plants had increased by 1919 to well over 400.

Since every ton of tar leaves on the average a residue of 10 cwts. of pitch in the still, it can be understood that this very rapid increase in the number of distillation plants has been accompanied by an equally rapid (and from the point of view of the producer undesirable) increase in the output of pitch. The price, in consequence, has fallen from its comparatively high level of 28*s*. 3*d*. per ton in 1914 to 20*s*. and 22*s*. per ton in 1919, for not only has the War doubled the production of pitch in this country, but it also closed, for the time being, two chief markets for its disposal abroad. Germany did not import pitch from the United Kingdom before the War, and therefore the loss of the German market was not of any importance; but the fuel briquetting industry in France, Belgium and Italy was largely dependent on the pitch obtained from the English and Scotch tar distilleries, and in 1913 our exports to France were valued at £472,000, Belgium, £297,000, and Italy, £119,000, a total loss of £888,000 to these three countries alone. This export trade, owing to the damage to the coal mines of Northern France and Belgium, will only revive very slowly.

This increase in the output of pitch during the War, and the fact that probably two million tons of this solid hydrocarbon are now produced annually in the tar distillation works of this country, has led to a revival of interest in the possibilities of pitch as a fuel, either for burning in the solid state under steam-boilers or for use in the liquid state in internal combustion engines. Before dealing with the practical methods of utilising pitch in this way, however, it may be advisable to review briefly its chemical and physical properties, since the question of its successful application as a source of motive power hinges largely upon a correct appreciation of the difficulties attending its complete combustion, either in the solid or liquid state.

THE CHEMICAL, THERMAL AND PHYSICAL PROPERTIES OF PITCH.

When coal tar is heated in the usual type of 20-ton still, in order to separate and recover the more valuable constituents, with boiling points below 270° C., a residue remains behind in the still, known under the trade name of pitch.

Chemically, pitch is a mixture of free carbon and of hydrocarbons containing oxygen, nitrogen and sulphur. The constitution of these hydrocarbons varies with the source of the tar, and also with the temperature to which the distillation has been pushed in order to recover the oils of lower boiling point. One ton of an average tar, under ordinary conditions of distillation, will yield the following products :—

Benzol	$\frac{1}{3}$	gallon.
Toluol	$\frac{2}{3}$	,,
Solvent naphtha	$1\frac{1}{2}$	,,
Heavy naphtha	1	,,
Carbolic acid (crude)	2 to 3	,,
Crude cresylic acid	2	,,
Creosote oils	20	,,
Anthracene oils	34	,,
Naphthalene	112	lbs.
Pitch	10	cwts.

The light oils distil at a temperature below 170° C., the carbolic or middle oils at temperatures lying between 170° C. and 230° C., and the heavy or creosote oils from 230° C. to 270° C. The anthracene oils only come over at higher temperatures (from 270° C. to 400° C.), and the distillation is not always carried so far as to remove these oils entirely from the pitch. A large portion of the pitch, 10 to 50 per cent., consists of finely divided carbon, but from 50 to 90 per cent. consists of solid unsaturated hydrocarbons of the aromatic type, which give the pitch its distinctive properties. According to Martin, the elementary analyses of hard and soft pitch yield the following figures :—

	Hard Pitch. Per cent.	Soft Pitch. Per cent.
Carbon	93·2	91·80
Hydrogen	4·4	4·60

The calorific value of pitch is extremely high, a sample tested by the writer in the bomb type of calorimeter having shown 15,928 B.Th.U., or a higher value than that of the best Welsh steam coal. This high calorific value is, however, counterbalanced by the production of a very high percentage of volatile hydrocarbons when it is heated, the following being an approximate analysis of a North Country pitch :—

	Per cent.
Moisture	·05
Ash	·60
Volatile matter	66·85
Coke	33·15
Fixed carbon	32·55

As regards the physical properties of pitch, the specific gravity varies from 1·20 to 1·35, the hard pitch produced when the distillation of the tar has been carried to a high temperature having the higher specific gravity.

The melting point likewise varies within wide limits ; but it must be noted that the term "melting point" when applied to pitch is an arbitrary one, since the material when heated gradually softens and passes by almost imperceptible stages into the liquid state. The extreme limits of melting point noted are 37½° C. in water and 174° C. in air ; but a pitch melting at 37½° C. (100° F.) would hardly deserve to be classed as a pitch, since this low melting point would signify that the distillation had only been carried far enough to drive off the water, the lighter oils, and some portions of the carbolic oils.

THE PROBLEM OF THE COMBUSTION OF PITCH UNDER STEAM BOILERS.

Pitch, as shown by the analyses given above, is composed chiefly of free carbon, and of hydrocarbons which become volatile on heating above 400° C. It is, therefore, combustible, and under proper conditions can be burned completely to CO_2 and H_2O vapour, with the production of heat equivalent to 15,900 B.Th.U. per lb. of pitch consumed. The very high percentage of volatile hydrocarbons which are evolved when it is heated above its melting point, however, renders it difficult to burn without the production of smoke, for even if the problem of keeping the air supply adequate for the complete combustion of these hydrocarbon gases be solved, there is still the difficulty of securing a proper admixture of the air and of the evolved combustible gases. These gases also are liberated at a lower temperature than in the case of bituminous fuel. This signifies that they require further heating before they reach the ignition point, otherwise they may escape from the furnace unconsumed, without yielding any of their heat value. This analysis of the difficulties of burning pitch as a solid fuel under steam boilers shows that special arrangements are necessary, and that it is useless simply to shovel the lumps of pitch mixed with the coal into the furnace and expect good steam-raising results from the mixture.

In fact, when such attempts are made to burn pitch in an ordinary furnace under Lancashire steam boilers, the pitch softens and melts, and closes the apertures and air openings between the fire-bars, before liberation or ignition of the gases has occurred. Dense volumes of black smoke are therefore produced by this cutting down of the air supply at the very moment when a large excess of air is required for efficient combustion, and the fire-side of the tubes of the boiler and economisers becomes covered with a thick oily deposit of soot, which reduces enormously the transmission of heat to the water. The hydrocarbons contained in coal, it may be observed here, pass from the solid to the gaseous state on heating without assuming this intermediate or liquid stage, and for this reason a highly bituminous coal is more easily burned than pitch.

The conditions required for burning solid pitch without excessive smoke production are :—

(1) An adequate supply of air, above or through the grate.

(2) An adequate mixture of this air and the evolved gases.

(3) Means for raising this large volume of air and hydrocarbon gases quickly to the ignition point of the latter.

The methods which have been adopted to secure these conditions in practice will now be described.

PRACTICAL METHODS OF BURNING PITCH UNDER STEAM BOILERS.

Mr. E. W. L. Nicol, of the London Coke Committee, has designed a special type of fire-bar for burning pitch in conjunction with coke under steam boilers. This bar is illustrated in Fig. 35, and a patent has been applied for. The special " pitch bar " consists of a series of channelled trough-shaped bars sloping gradually from the front end to the deepest point, A-B, where the section is taken, and having beneath them a steam-jet blower.

Some of the ordinary fire-bars of the furnace are removed, and "pitch-bars" substituted, the number and distance apart of the latter depending upon the character and volatile matter contained in the fuel that is being consumed on the other portions of the furnace grate. The pitch, broken to a convenient size, is fed on to the front end of these special "pitch-bars," preferably by some type of mechanical feed, which will maintain a regular supply without opening the furnace door. The heat of the surrounding fire causes the pitch first to melt and to flow down the sloping channel of the bar to the portion marked A-B and then to volatilise. The rate of such volatilisation is said to be controlled by the form of the bars, and the forced draught supplies the surplus heated air which is required to secure the combustion of the hydrocarbon gases produced from the molten pitch. The partially coked residue which remains after the more volatile constituents have been driven off and burned is then pushed on to the rear portion of the grate, where its combustion as ordinary coke offers no special difficulties. The bar and necessary accessories are made by Messrs. Ross and Schofield, of London.

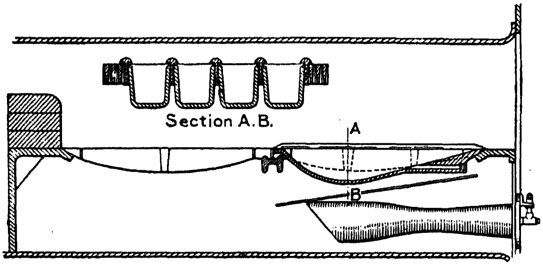


FIG. 35.—Nicol's special type of Fire-bar for burning Pitch.

Pitch is also being burned in a tar distillation works in the North, in conjunction with breeze and coal, under Lancashire steam boilers, in the proportions of 75 per cent. breeze, 18 per cent. pitch, and 7 per cent. coal, without any trouble from smoke. The boilers in this case are hand-fired and work under natural draught; but it will be observed that the proportion of pitch is only about one-sixth of the total weight of fuel used, and as the breeze evolves only a comparatively small amount of hydrocarbon gases, the final volume of combustible gas to be consumed is not large.

At one time this firm employed a mixture consisting of 45 per cent. crushed pitch and 55 per cent. breeze. The steam-raising value of this mixture was good, but it produced smoke, and in time resulted in an oily deposit of soot on the economiser tubes, which could not be removed by the scrapers and had eventually to be burned off. Probably if this firm had installed forced draught apparatus, with a preheated air supply, this half-and-half mixture of pitch and breeze could have been burned without any trouble, since a deficient air supply was undoubtedly the cause of the sooty deposit.

PITCH AS A LIQUID FUEL.

Mixtures of Pitch and Creosote Oil.

The use of pitch and creosote oil mixtures as a liquid fuel for steam-raising purposes has been submitted to practical trials during the last few years, under the stimulus of the Admiralty officials, who have been anxious to preserve the limited supplies of creosote and other ordinary fuel-oils for naval use.

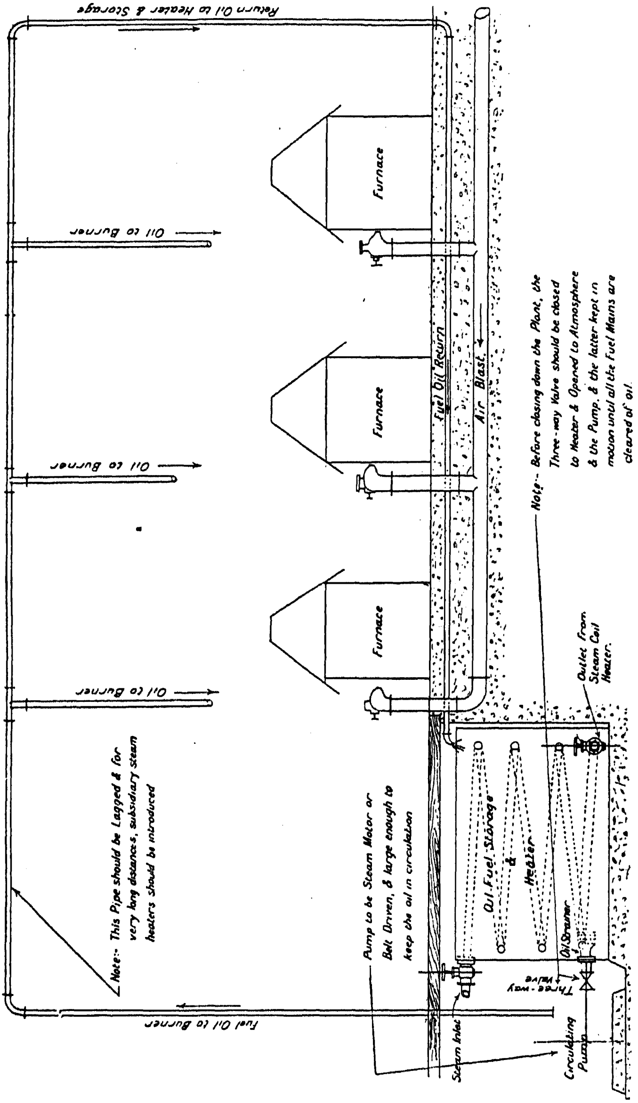
The Wallsend Slipway and Engineering Company are stated [1] to have been quite successful in burning mixtures containing 65 to 70 per cent. of pitch in a pressure-jet type of burner, the boiler being worked under natural draught conditions and showing an efficiency of 80 per cent. The pitch in the supply-tank was kept liquid by steam coils at a temperature of 130° F., the pressure used for the jet was 75 lbs. per square inch, and the temperature of the pitch and creosote mixture was raised to 290° F. at the burners before being atomised. The furnace temperature attained in these trials was stated to be 1,800° C. (3,272° F.).

Messrs. Lyons & Co., at their Kensington (London) Works, have also burned mixtures of pitch and creosote in the proportion of 30 : 70, and have obtained boiler efficiencies of

---

[1] See article in *Engineer*, April 19th, 1918.

82 per cent. with the fuel, the system of burning used in this case being that known as the White system.



Note:- This Pipe should be Lagged & for very long distances, subsidiary steam heaters should be introduced

Pump to be Steam Motor or Belt Driven, & large enough to keep the oil in circulation

Note:- Before closing down the Plant, the Three-way Valve should be closed to Heater & Opened to Atmosphere & the Pump. & the latter kept in motion until all the Fuel Mains are cleared of oil.

FIG. 36.—Diagram of a Furnace Plant for Pitch and Creosote Mixtures.

Pitch and creosote mixtures have also been used successfully by several firms for heating metallurgical furnaces, and the only barrier to the extensive use of pitch as a fuel is that due to the well-known difficulty of handling and transporting it, and to the presence of impurities which tend to choke up and stop the strainers attached to the burners.

The article quoted above discusses these difficulties, and Fig. 36 shows how the pitch can be kept sufficiently liquid during its passage from the supply-tank to the burners.

The problem of the transport of the pitch in a liquid state by tank-waggons—from the tar distillation works to the points where it is to be used, offers more difficulty, but there is no doubt this problem could be solved if engineers devoted sufficient attention to it. One solution would be the production by tar distillers of a "soft pitch" specially for fuel purposes, with a very low melting point, and the provision of tank-waggons with double walls packed with some heat insulating material. If the "soft pitch" were run or pumped into these waggons with a temperature of 150° F. it could be carried long distances before solidification occurred.

The distillation of the tar in this case would be stopped when the light and middle oils had been distilled (that is at 200° C.), and the soft pitch which remained in the still would be utilised in the semi-liquid state in a modified form of the usual atomising form of injector, using hot air under pressure as motive power. The pre-heating of the air supply and the thorough admixture of the minute globules of liquid pitch and the air could be most effectively carried out by this system of combustion.

In this connection the patent of Mr. Arnold Philips, an Admiralty chemist at Portsmouth, for reducing the viscosity of thick oils may be referred to. In this patent (No. 14,778 of 1913) the addition of 8 per cent. of naphthalene is specified for rendering certain thick oils more suitable for fuel purposes. If the naphthalene be left in the pitch it is reasonable to suppose, therefore, that it will also have the same effect in rendering the latter more suitable for atomising purposes. Should difficulties from cooling and partial solidification occur in the spraying nozzle they no doubt could be overcome by enclosing the latter in a heat-insulating jacket, through which pre-heated air or superheated steam would be passed before entering the atomising nozzle.

As regards recent patents dealing with this subject, British patent No. 101,444 of 1916, granted to G. H. H. Bölling, of Christiania, describes a method of melting the pitch by means of the heat of a steam coil, and introducing it through similarly heated pipes into the furnace, where it is atomised by a jet of steam or air. The steam jackets, pipes, and valves are so arranged that any incrustation may be removed. German patent No. 290,708 of 1914, granted to Robert and Trinyi, relates to the similar use of powdered pitch as a fuel, the pitch in this case being blown into the furnace in the form of dust. Finally, the British patent of G. Heyl (No. 110,023 of 1916) may be referred to. According to this, liquid fuels suitable for firing furnaces and for use in high compression oil engines can be manufactured with the aid of pitch, by treating mineral oils and heavy creosote oils with solid caustic soda, to neutralise the acids present and to remove sulphur compounds. The oil is cooled to eliminate the naphthalene (a mistaken proceeding in the light of Philips' discovery) and is then heated with pitch. It is stated that up to 50 per cent. of the latter by weight can be dissolved by this method of procedure.

THE USE OF PITCH AS A FUEL FOR INTERNAL COMBUSTION ENGINES.

One method of rendering pitch sufficiently fluid to be used in internal combustion engines is described above, and it is highly significant that the Controller of the Mineral Oil Production Department of the Ministry of Munitions is now arranging for trials of mixtures of pitch and creosote, in order to test their suitability for internal combustion engines. When used in the ordinary way such mixtures are not very satisfactory for Diesel engines, owing to starting difficulties and to incomplete combustion in the engine cylinder. If burned, however, with the aid of a Mirlees Bickerton and Day, or other form of "pilot ignition" apparatus, they give quite good results. With this apparatus, 5 per cent. of petroleum oil is injected into the cylinder just before the creosote and pitch mixture enters; and this pilot charge of a more easily ignited oil enables the temperature to be kept sufficiently high to obtain proper combustion of the composite heavier oil, that follows it into the cylinder.

The chief difficulty in using heavy oils in gas engines is, of course, to prevent imperfect combustion, and the consequent choking of valves, etc., with deposited carbon. Should this occur, the use of a mixture of wood spirit and ammonia has been patented for removing these deposits without the application of heat; but the writer is unable to state whether this mixture has proved satisfactory in practice. Burning off, the usual plan, is, of course, efficacious, but it is troublesome, and a liquid agent which would act in the cold would have much in its favour.

THE LINES OF FUTURE PROGRESS.

This summary of the most recent patents and experience relating to the use of coal tar pitch as a fuel for steam boilers and for internal combustion engines shows that some progress is being made. The methods of rendering pitch sufficiently fluid to be used in atomisers are in the opinion of the writer the more hopeful, and he is less confident that pitch can be used economically in the solid and pulverised condition for firing steam boilers.

The fact that pitch softens at a comparatively low temperature means that the heat generated by friction in the pulverising apparatus will have to be dissipated by artificial cooling, to prevent the grinding surfaces becoming clogged with half melted pitch, and this artificial cooling must add considerably to the costs of the grinding operation. In the methods of rendering pitch more fluid, on the other hand, the heat added to the material is of direct service in accelerating and improving the after combustion in the boiler furnace or engine cylinder, and consequently the heat is not wasted, but is preserved and made effective at a later stage of the combustion process.

It would seem, however, a waste of time and of heat energy to first separate the constituents of coal tar by distillation into four or five separate portions, and then to recombine some of these portions in order to obtain a mixture suitable for use as a liquid fuel. The author considers therefore that the future line of development will be to carry the distillation only far enough to win the lighter oils and the phenols from the raw tar, and that the residue from the stills, containing the heavy creosote oils, the naphthalene and the pitch, will then be sold and utilised as a liquid fuel. The anthracene oils, which are the last constituents of the raw tar to distil over (270° to 400° C.), would in this case be left in the pitch, and only when the demand and price offered for the anthracene made its extraction more profitable, would the complete distillation of the raw tar and separation of all the possible classes of its constituents be carried out.

CHAPTER VIII

WASTE GASES FROM COKE OVENS AND METALLURGICAL FURNACES

THE heat carried away in waste gases may exist either as "sensible heat," *i.e.*, heat measurable by the thermometer, and due to the failure to extract from the gases the whole of the heat generated by the combustion of the fuel; or as "potential heat," *i.e.*, heat represented by chemical energy, due to the incomplete oxidation of the combustible matter, and to the presence of hydrogen, methane and carbonic oxide in the escaping gases. In the latter case, some form of burner and combustion chamber, with means for regulating the air supply, is necessary, whereas when the waste gases carry only "sensible" heat, and combustion is completed, the addition of a boiler or economiser only is required to save some portion of the wasted heat.

The gases from metallurgical furnaces and from heating installations generally are examples of the first, and the gases from coke-ovens, blast-furnaces and from certain types of steel-reheating furnaces (in which a reducing atmosphere is required) of the second. There is, however, no hard and fast line of distinction between the two classes in practice, for the gases from coke-ovens and blast-furnaces carry always some "sensible" heat to the boilers in which they are utilised; and unburned carbon monoxide and hydrogen are present at times in the waste gases from ordinary furnaces and boilers.

Many forms of burner have been devised for supplying the necessary air to the combustibles in the particular gas that is being employed for steam-raising, and as this gas may vary considerably in richness (as shown by the analyses given below) the burners must be provided with mechanism for increasing or diminishing the air-supply within wide limits. Figs. 37 and 38, show different forms of burner for the combustion of waste gases under boilers—and from these it will be seen that they resemble one another in principle, and differ only in details of construction.

The two chief necessities are to obtain a thorough admixture of the gas and air and to keep down the excess of air to the lowest possible percentage consistent with good combustion. The proper management of the firing in gas-fired boilers demands therefore considerable intelligence, and regular testing of the exit gases, since there is no smoke-emission to warn the engineer or chemist in charge when the air supply is deficient and gases are passing up the chimney incompletely consumed.

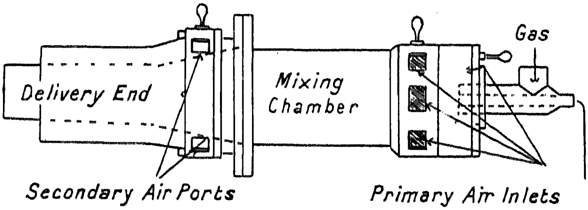


Fig. 37.—Altenheim & Wilson Burner for Producer Gas.

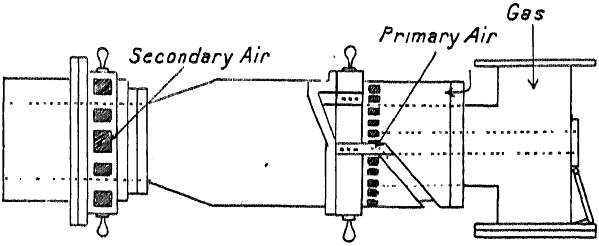


Fig. 38.—Altenheim & Wilson Burner for Blast Furnace Gas.

If an excess of air be admitted also into the mixing-tube or compartment of the burner " back firing " will occur, which with large volumes of gas is a distinct danger both to the firemen and to the fabric of the boilers, while if too little primary air be admitted some considerable portion of the gases will escape combustion.

Both practical experience and chemical knowledge are required therefore if boilers fired with coke-oven or blast-furnace gases are to yield their maximum of steam, and it is doubtful whether the larger portion of the waste-heat steam plant installed in this country and America is being worked at a high efficiency, simply because the expert knowledge and experience required to operate it is lacking.

In the earlier installations of waste-heat boilers the natural chimney draught was relied upon to overcome the increased resistance due to the passage of the gases through the flues of the boiler. In many cases the boiler was erected directly above the furnace, in order to minimise the losses from this cause. This plan was never entirely satisfactory, and in modern installations artificial draught is always employed. In this way the draught of the original apparatus or furnace is increased rather than lessened by the installation of the waste-heat boilers, and the use of the fans also enables much higher gas velocities to be attained over the water-cooled plates of the boiler, and increases considerably the rate of heat transmission, and therefore the efficiency of the whole plant.

As regards the practical value of waste-heat boilers, it is possible with a modern plant to reduce the heat of the waste gases to 500° F. Any furnace, therefore, which is allowing gases to pass away above this temperature, may be provided with the necessary plant for recovering the waste heat, although as a general rule it only pays to recover the heat when the gases are carrying 200° or 300° F. of surplus heat up the chimney.

In the United States it is calculated that the utilisation of the waste heat from open-hearth and other regenerative furnaces in the steel-making plants is equivalent to a saving of 250 lbs. of coal per ton of ingots produced, or to an annual saving of two million tons of fuel. Of the total heat delivered to the open-hearth furnace, 45 per cent. is wasted in chimney losses, and from one-half to two-thirds of this heat can be recovered by the installation of waste-heat boilers.

The following tabular statement shows the chemical composition, thermal value, and "sensible" heat of the waste gases from typical iron, steel, and other metallurgical furnaces :—

TABLE I.—THE CHEMICAL COMPOSITION AND THERMAL VALUE OF WASTE GASES CONTAINING COMBUSTIBLE CONSTITUENTS.

Type of gas.	Per cent. H.	Per cent. CH_4.	Per cent. CO.	Per cent. C_2H_4.	Calorific value.*
Coke-oven gas . .	49·1	32·6	8·1	3·1	535
Blast-furnace gas . .	3·5	—	25·4	—	90 to 115

* In British thermal units per cubic foot of gas.

TABLE II.—THE SENSIBLE HEATS OF WASTE GASES CONTAINING NO COMBUSTIBLE CONSTITUENTS.

Source of gas.	Temperature, deg. Fah.
Open-hearth steel furnaces . . .	1100—1300
Reheating furnaces	1100—1900
Cement kilns	1300—1800
Copper refining furnaces . . .	1400—2200

The following practical examples of waste heat utilisation for steam generation are drawn from the United Kingdom, Belgium, Germany, and the United States ; those examples being selected in which the data of test results are the most reliable and up-to-date.

UNITED KINGDOM.

Although small isolated installations of boilers utilising the waste heat from coke-ovens and blast-furnaces, or from furnace operations in chemical works, had existed in the United Kingdom prior to 1907, the most notable development occurred in that year in connection with the coke-ovens and blast-furnaces erected in the South Durham coalfield. "The Waste Heat and Gas Electrical Generating Stations, Limited," was formed in 1907, to promote the use of waste heat for power purposes, and this Company has developed so satisfactorily that it now controls nine of the waste-heat power stations running in the South Durham area. Its success is proved by the fact that it has paid 8 per cent. on its ordinary share capital for the past few years, and has accumulated a reserve fund of £70,000 to provide for future contingencies. According to R. P. Sloan, who contributed a paper on the subject to the 1916 meeting of the British Association at Newcastle, there were at that date eleven waste-heat power stations operating in the North-East Coast area, and two of these alone turned out 40,000,000 units of electricity per annum. The problem of utilising the waste heat from iron and coke-oven plants has therefore been solved satisfactorily in this district, and has led to savings which are estimated to be equivalent to 150,000 tons of fuel per annum.

The waste-heat stations in the North-East Coast scheme operate in conjunction with the County of Durham Electrical Power Supply Company, and also with the Cleveland and Durham County Electrical Power Company, the area served by these two power companies extending to 1,400 square miles, and the total energy supplied at present being 343,000 H.P. The waste-heat stations are placed close to the larger coke-ovens and blast-furnace plants, and operate in parallel with the five main stations of the power companies. They are run at their maximum capacity, and all regulation of the power is effected by the main supply stations. The main distribution and transmission system is three-phase, and the working pressure is 20,000 volts. The power is utilised chiefly in the engineering shops and shipbuilding yards situated on the Tyne and Wear, and as the purchasing companies have a market for their current many times greater than the output of any individual waste-heat station, it is possible to run these stations continuously at their full capacity, and to utilise to the best possible extent the machinery installed in them. Unfortunately for scientific purposes no figures have been published, or can be obtained, for the thermal or working efficiency of these North-East

Coast waste-heat stations, and therefore it is impossible to say how the system adopted compares in practical value and economy with the waste heat stations situated in other countries. As the most notable and financially successful scheme of waste heat utilisation in the United Kingdom, however, the North-East Coast developments deserve first mention in any reference to the subject.

The Blaydon and Rowlands Gill Developments.—In 1904 by-product coke ovens were erected at the coking works attached to the Priestman Collieries at Blaydon, near Newcastle, and a complete installation of water-tube boilers was added in order to utilise the waste heat of the ovens. At Blaydon there are ninety ovens, and the steam produced from the waste heat is employed to generate electricity in an up-to-date power station, which is worked in co-operation with the Newcastle Electric Supply Company's stations. At Rowlands Gill there is an installation of 200 beehive ovens, and in 1909 nine Stirling water-tube boilers were erected on the main flues which carried the waste gases from the ovens to the chimney. Two Bettington tubular boilers and four Stirling boilers, fitted with underfeed stokers, were added for the purpose of burning coke ballast—one of the waste products of the coking works—and also to provide an alternative source of steam power when the ovens were not working.

The electric power station at Rowlands Gill contains four Westinghouse turbines, coupled to three-phase alternators, generating current at 6,000 volts for supply to the Newcastle Alloy Company's Works in the vicinity of the generating station. As regards the working efficiency of the Rowlands Gill boilers, the following are figures given by A. D. Pratt in a valuable and important paper read before the American Society of Mechanical Engineers, in New York, on December 16th, 1916. The test, it may be explained, was made on one of the Stirling boilers rated at 161 H.P., and worked in connection with twenty-two beehive ovens producing coke from an average of 3,800 lbs. coal per hour, or 173 lbs. per oven per hour.

Heating surface	1,610 square feet.
Gas weight	23,200 lbs. per hour.
Gas per square foot of heating surface	14·4 lbs. per hour.
Temperature—	
Entering boiler	1,720° F.
Leaving boiler	650° F.
Drop in temperature	1,070° F.
H.P. developed	187° F.
Approximate rate of heat transfer	4·7 B.Th.U. per square foot per hour per degree of temperature difference.
Draught (natural chimney draught)	·56 inch.

BELGIUM.

The famous Cockerill Company, of Liège, started experiments in 1909 with the object of utilising the heat contained in the waste gases from the large gas engines working with blast-furnace gases, the heat in these gases being estimated to amount to 650 calories per horse-power hour. The type of boiler the engineers of the Cockerill Company evolved for the purpose consisted of a horizontal tubular boiler surmounted by a vertical tubular economiser. The gases which left the engine with a temperature of 446° F. entered the boiler and were reduced in the economiser to 230° F., while the water was heated up from 46° F. to 338° F. The water then passed into the boiler, where it was converted into steam at a pressure of 114 lbs. per square inch. Four boilers of this type had been installed by the Cockerill Company before the War broke out, and were developing 5,000 H.P. Steam was raised in the proportion of 1·93 lbs. per E.H.P. developed by the gas engine, and it was estimated that the boilers recovered 55 per cent. of the heat of the waste gases, and increased the thermal efficiency of the gas engines by 13 per cent.

The late M. Greiner calculated that with four gas engines of 1,500 H.P. each the savings effected by the installation of waste-heat boilers would amount to £3,880 per annum. If it be accepted that a thermal efficiency of 30 per cent. can be obtained in the gas engine, then the addition of a waste-heat recovery plant would raise the efficiency to 35 per cent., or to double that of the best steam plant.

GERMANY.

As customary, most of the German records of trials and tests of waste gases for steam-raising purposes are more scientific and exact in their form than those of other countries. The most important and valuable of the results for comparative purposes are those recorded by Butow and Dobblestein in the mining paper *Gluckauf*. The tests related to trials with the Wefer patented system of boiler firing with coke-oven gas. This system was designed to secure a better mixture of the combustible gases and air passing into the boiler furnace, and also to minimise the risks due to back-firing, or to explosions in the mixing chamber. In the early types of burners for boilers fired with coke-oven gas, the gases were introduced by simple nozzles, air being supplied through openings in the furnace front. Imperfect mixing of gas and air led to imperfect combustion.

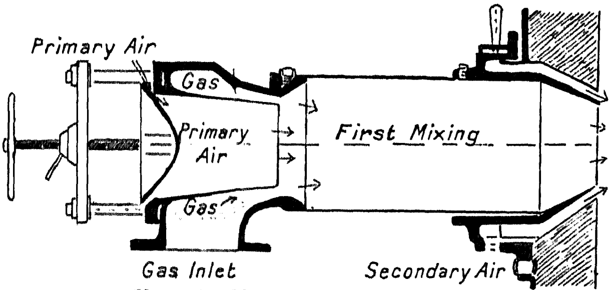


FIG. 39. The Terbeck Gas Burner.

Fig. 39 shows the construction of the Terbeck burner, one of the first designed to secure a better admixture of the gas and air. It will be seen from the sectional drawing of this burner that it is constructed on the Bunsen burner principle, and that the primary air-supply is controlled by a ring-shaped valve, while a secondary air-supply is provided at the point where the mixed gas and air enter the combustion chamber of the boiler. By the substitution of this burner for that hitherto employed at the colliery where these tests were carried out, Butow and Dobblestein obtained nearly double the evaporation per square foot of heating surface per hour, the increase being from 1·47 lbs. to 2·93 lbs., and the steam output per ton of converted coal rising from 782 lbs. to 1,320 lbs. These figures prove conclusively that with the older methods of burning coke-oven gases for steam generation enormous waste of heat had occurred from excessive or deficient air supply. The Terbeck burner, however, while quite efficient for regulating the air supplied to the burner, and for obtaining a good admixture of the gas and air, did not provide adequately for the explosions due to back-firing — and in order to provide for this contingency the Wefer burner was brought out in Germany.

In the Wefer system, gas flows from the main into the twenty-five iron pipes feeding the graphitic burner tubes through a chamber, one end of which is formed by a hinged explosion cap. This uncovers the full section of the chamber in case of back-fire, and closes automatically when the latter has expended its force. It also affords thorough access to the burner tubes. Air is supplied through a ring valve to a separate chamber, whence it flows concentrically with the gas tube for a distance, and is thus thoroughly mixed with the gas before ignition. An eight-hour test on a double fire-flue boiler of 1,280 square feet heating surface gave the following results—summarised :—

Steam pressure (gauge)	178 lbs.
Steam temperature	311° C.
Mean gas pressure	3·5 inches water.
Mean gas temperature	27° C.
Mean calorific value of gas	461 B.Th.U. per cubic foot.
Excess air supply	1·71.
Evaporation from and at 100° C.	286·5 lbs. per 1,000 cubic feet of gas.
Evaporation per square foot heating surface	4·47 lbs. per hour.

Thermal efficiency	71 per cent. (to saturated steam).
	8·2 per cent. (in superheat).
Total	79·2 per cent.

Forty-eight Wefer furnaces, in 1912, had been in satisfactory operation at the Victor Pit, Rauxel, for nine months. Assuming a boiler of 120 square metres heating surface to yield 18,000 tons of steam during 300 working days, it is shown that the costs per metric ton of steam are :—Wages, 3 pf. ; maintenance and cleaning, 2 pf. ; feed-water, 5 pf. ; interest and depreciation, 10 pf. ; total, 20 pf. per ton (2⅜*d.*). This figure may be compared with the average estimate of 1·6 marks (18*d.*) per ton of steam, in coal-fired installations.

Another series of trials carried out in 1914 with an improved form of Wefer burner gave the following results, the tests being carried out on a boiler with both fire-tubes fitted with the new burner :—

Heating surface	1,241 square feet.
Gas analysis—	
CO_2	1·6 per cent.
O	1·8 ,,
CO	4·6 ,,
H	52·2 ,,
CH_4	28·8 ,,
Heavy hydrocarbons	1·6 ,,
N	9·4 ,,
Mean calorific value	428 B.Th.U. per cubic foot.
Gas pressure	5·8 inches (water) at 35° C. ; barometer, 29·7 inches.
Flue gases—	
CO_2	8·3 per cent.
O	3·24 ,,
CO	Nil.
Excess air ratio	1·16.
Furnace temperature	1,425° C.

Steam pressure	12 atmospheres (gauge); 297° C. at superheater.
Steam produced	7,219 lbs. per hour.
Gas	24,854 cubic feet per hour.
Evaporation	291 lbs. per 1,000 cubic feet of gas and 5·81 lbs. steam per square foot heating surface per hour.
Thermal efficiency to saturated steam	77·6 per cent., including superheat, 84·6 per cent.
Loss by conduction and radiation	15·4 per cent.

Comparison with the earlier test data shows a net gain of 3·4 per cent. in the thermal efficiency, despite the increase in evaporation from 4·47 lbs. per square foot to 5·81 lbs.

In the improved Wefer burners used for these tests the coke-oven gases flow from the gas chamber through forty distributing tubes, and are delivered about two-thirds the distance along tunnels in the graphite burner block. The use of forty distributing tubes in place of the twenty-five of the earlier burner secures a better mixture of the gas and air. The latter is admitted through a ring-valve, and flows concentrically with the gas tubes to the mixing chamber at the burner head. The original form of Wefer burner extended into the fire-tube of the boiler for a distance of 2 feet, but the improved form is built on to a tubular extension of the furnace front, and thus the whole length of the fire-tube of the boiler is available for heat transfer.

To provide for back-firing and explosions a central tube 8 inches in diameter is inserted in the burner, with a simple explosion valve on its outer end. The combustion chamber is lined with fire-brick, and in order to promote more perfect combustion of the gases, a perforated plate and a bank of short tubes of fire-clay are mounted in the fire-tube of the boiler. At the Victor Pit, where these trials of the Wefer burner have been carried out, a gasometer with a capacity of 1,400,000 cubic feet has been erected in order to secure a steady pressure of gas when delivered to the burners. As the gas is now being stripped of all its benzol in a by-product recovery plant, the thermal value of the gas is not so high as it was at the time of the tests.

In comparison with the above tests of the Wefer burner, figures given by Ortmann in the August, 1913, issue of *Stahl und Eisen* for the results of tests made with blast-furnace and coke-oven waste gases may be quoted. The boiler used for blast-furnace gas had 968 square feet of heating surface, and was provided with an economiser. The thermal efficiencies in three separate tests were 79·4 per cent., 76·8 per cent., and 82·7 per cent., giving a mean of 79·6 per cent. The other boiler had a heating surface of 925 square feet, and showed in two separate tests efficiencies of 74·9 per cent. and 80·2 per cent., when fired with coke-oven gas, the mean in this case being 77·5 per cent. The calorific value of the gases and other details are not available in this case, so it is impossible to say whether the burner used was as efficient as the Wefer burner.

UNITED STATES.

Although America possesses no plant or scheme so notable as that found in the South Durham coal and iron districts for the utilisation of waste heat, a large amount of practical work has been carried out, and in a paper presented at the 1916 annual meeting of the American Society of Mechanical Engineers Mr. A. D. Pratt gives a useful review and summary of what has been achieved in connection with this problem across the Atlantic.

The design and operation of boilers for utilising the waste heat of open-hearth steel furnaces, cement kilns, copper furnaces, beehive coke ovens, and heating furnaces generally, are discussed in this interesting paper, and from it the following particulars are extracted of the waste heat installation at the plants of the H. C. Frick Coal and Coke Company, at York Run, Pa., and of the Indiana Steel Company, at Gary, Ind.

At York Run fifty beehive coke ovens are connected to three Stirling boilers provided with standard type of baffles, and 3,600 square feet of heating surface each. The test extended over a full week's run of 168 hours, and there were on the average forty-four ovens in service, coking coal at the rate of 13,800 lbs. per hour, or 314 lbs. per oven per hour. The weights of gas and temperatures varied considerably during the week, the lowest temperature noted being 1,500° F., and the highest 2,075° F. The exit temperatures varied from 475° F. to 550° F., and averaged 490° F. The gas consumed in this test, expressed as lbs. per hour, was 83,650, and expressed as lbs. per hour per square foot of heating surface, was 7·7. The drop in temperature of the gases in passing through the boilers was 1,314° F., and the horse-power developed amounted to 824, or 76 per cent. of the rated capacity of the boilers. The approximate rate of heat transfer was 3·2 B.Th.U. per square foot per hour per degree of temperature difference.

The above represents the results obtained with an early installation of boilers for utilising the waste gases from beehive ovens, and later installations in the United States of America show considerable improvement upon these results.

At a more modern plant, provided with a specially designed Babcock & Wilcox boiler, eighteen sections wide, each section made up of 26 feet by 20 feet tubes, and thus providing 10,200 square feet of heating surface, the draught is furnished by a turbine-driven induced draught fan, and a much higher rate of heat transfer is obtained, due to the greater speed at which the gases are passed through the boiler. The results of two tests with this boiler are shown on p. 137.

The performance of this first boiler has been so satisfactory that six additional units have been ordered by the owners of this coking plant, the only difference being that there are twenty-seven sections instead of eighteen, and that each boiler possesses 15,300 square feet of heating surface, equivalent to a capacity of 9,180 H.P. for the six units.

The utilisation of the waste heat from open-hearth steel furnaces has been practised for many years in America, and according to Pratt (see paper already quoted), there are already installed or on order boilers capable of producing 90,000 H.P. from this type of waste heat alone. These boilers are connected to 190 open-hearth furnaces which produce annually over nine million tons of steel, and experience has shown that through the use of these waste-heat boilers the net cost of production is reduced by 20 to 25 cents per ton, and that a total economy of 1,840,000 dols. is earned on the above output of steel. The fear that the installation of waste-heat boilers, with their fans and other accessories, would cut down the production of the open-hearth steel furnace has proved groundless, for the figures show that the improved draught resulting from the use of fans leads to a reduction in the time of the separate heats, and increases the tonnage capacity of the furnace.

	No. 1.	No. 2.
Gas consumed, lbs. per hour	125,500	155,100
Gas per square foot of heating surface per hour	12·2 lbs.	15·2 lbs.
Temperatures—		
Inlet to boilers	2,329° F.	2,158° F.
Exit from boilers	463° F.	477° F.
Drop in temperature	1,866° F.	1,681° F.
Power developed	1,750 H.P.	1,956 H.P.
Per cent. of rated capacity of boiler	172	192
Approximate rate of heat transfer *	5·6	6·8

* Expressed as B.Th.U. per square foot per hour per degree of temperature difference.

The installation of waste-heat boilers at the Gary Works of the Indiana Steel Company consists of twenty-eight special six-drum Rust type of boilers, equipped with special cross baffles, in order to give the desired gas velocities over the heating surfaces. Each boiler has a heating surface of 4,880 square feet, and that to which the following test relates developed under test 393 H.P., or 80·6 per cent. of its rated capacity :—

Gas weight	83,434 lbs. per hour.
Gas per square foot of heating surface	17·1 lbs. per hour.
Temperatures—	
Entering boiler	1,155° F.
Leaving boiler	530° F.
Drop in temperature	625° F.
Draught at boiler inlet	1·47 inches.
Draught at boiler damper	3·95 ,,
Loss in draught	2·48 ,,
Approximate rate of heat transfer	6·92 B.Th.U. per square foot per hour per degree of temperature difference.

PART II.—SCIENTIFIC CONTROL

CHAPTER IX

FUEL SAMPLING AND TESTING

IT is an accepted truism that the sampling of any commercial product is quite as important as the analysis of the sample obtained ; for if the sample be badly taken, and therefore be not representative of the bulk, the results from the commercial standpoint are valueless.

It is necessary, however, to repeat this caution when writing upon the subject of scientific standards of fuel valuation, for part of the suspicion with which the new system is regarded is attributable to the faulty and slipshod methods of sampling that have been adopted in the past, and to the unfair valuation of the fuel based on the test results obtained in these cases.

The sampling of a 100- or 1,000-ton delivery of fuel requires to be carefully carried out by a properly trained man, in accordance with certain definite rules, if the sample finally obtained is to be representative of the whole delivery. The widely prevalent idea that any man armed with a shovel can sample fuel must be eradicated before much progress along the lines of scientific valuation can be made. The objection urged against employing properly skilled men for sampling is, of course, that of expense. If the thing is to be done at all, however, it must be well done ; and the saving effected by employing unskilled labour is negligible when compared with the amount of money involved.

Naturally, there comes a point in the purchase of fuel when the cost of sampling and testing is too heavy in relation to the value of the fuel bought to render the system economical or practical. Every fuel contract over 100 tons, however, carries enough profit to pay for sampling and testing, and if the cost of the latter be divided between all the parties to the contract it is too small to be of any importance.

A skilled and trained sampler with two or three unskilled labourers, and proper equipment, can control the regular sampling of 1,000 tons of fuel per day, and, if necessary, could look after the interests of two or three purchasers at the same yard. The man selected as head of the gang, however, must be well paid ; for the work is of great importance and demands a high degree of intelligence. Professional samplers also have more need of strong character and moral backbone than the ordinary man, since attempts to bribe them to betray their employers' interests are customary and very often successful. A good and honest sampler is therefore well worth his wages and should be treasured by his employers when once found.

METHODS OF SAMPLING SOLID FUELS.

The fundamental principle or aim of all sampling is to obtain a small portion of the material to be sampled which shall be thoroughly representative of the original car, truck, load or heap of fuel. This can only be secured by the exercise of great judgment and care in the sampling work. There are three conditions which must be observed in order to obtain a fair sample of fuel containing both large and small lumps :

1. The original sample taken must be large enough to represent all portions of the bulk, and a fair proportion between large and smalls must be maintained.

2. The sample must be reduced by repeated crushings, mixings and quarterings to the small quantity required for the actual test.

3. In order to continue the crushings and quarterings up to the required degree of fineness, it is necessary to dry the sample at some intermediate stage. A wet or damp sample of fuel cannot be ground to pass through a 60-mesh brass wire sieve, which is that used for the final stage of fuel sampling.

When fuel is shipped and samples have to be collected from cars or barges, a large sample, varying from 600 to 1,500 lbs., will be required. It must also be remembered that the jolting of a railway car will send the small coal and dust to the bottom. In a barge the finer coal and smalls are found most generally in the centre of the cone-shaped pile or heap of fuel under each hatch, and the large lumps are found round the base of the conical heap. In neither case, therefore, can a fair sample be obtained by merely taking a shovelful from various parts of the top of the car, or outside of the heap. It is only on discharge of the fuel that a fair sample can be obtained.

G. S. Pope, in Bureau of Mines Bulletin No. 63, on the "Sampling of Coal Deliveries," gives the following directions concerning the collection of gross samples of fuel :—

"When coal is being unloaded from waggons, railroad cars, ships, or barges, a shovel or a specially designed tool may be used for taking portions or increments of 10 to 30 lbs. to make up the gross sample of coal. As the size of the increments should be governed by the size and weight of the largest pieces of coal and impurities, increments of more than 30 lbs. may be required for coals containing large pieces of coal and impurities.

"The portions should be regularly and systematically collected, so that the entire quantity sampled will be represented proportionately in the gross sample. The interval at which the portions are collected should be regulated, so that the gross sample collected will weigh not less than approximately 1,000 lbs. If the coal contains an unusual proportion of impurities, such as slate, bony coal and pyrites, and if the pieces of such impurities are very large, it will be necessary to collect gross samples of even 1,500 lbs. or more ; but for slack coal and for small sizes of anthracite, if the impurities are not in abnormal proportion or in pieces larger than about $\frac{3}{4}$ inch, and if the impurities are evenly distributed throughout the coal, a gross sample of approximately 600 lbs. may prove sufficient. The gross sample should contain the same proportion of lump coal, fine coal and impurities as the coal delivered. As the portions are collected they should be deposited in a receptacle having a tight-fitting lid provided with a lock.

"A gross sample taken by hand from coal delivered by waggon at a Government building should consist of shovelfuls of coal taken from every first, second or third waggon load as it is being discharged, the number of shovelfuls taken and the loads sampled being dependent on the number of loads which the gross sample is to represent. If the coal is discharged immediately into a crusher, it is preferable to collect shovelfuls of the crushed coal.

"Samples taken from railroad cars should not be limited to a few shovelfuls of coal procured from the top of a car, for the size of the coal and the proportion of foreign matter may vary from the top to the bottom of the car. The only way to obtain a representative sample is to take a number of shovelfuls or portions of coal from different points in a car, from top to bottom and from end to end, while the coal is being unloaded.

"In sampling cargoes, as in sampling carloads, portions of coal should be taken in equal quantities and at frequent and regular intervals, so as to represent proportionate parts of the consignment as a whole, either while the coal is being loaded or unloaded. There is no assurance that a sample or a series of samples taken from the top of the cargo represents the cargo as a whole; in fact, it is very doubtful if such samples are ever representative."

The crushing, mixing and reduction of the sample to a smaller bulk may be either carried out by hand or by crushing machinery. Where a large number of samples have to be dealt with, some form of mechanical crusher is essential.

In small works and boiler houses, where no mechanically operated crusher is available, however, the following method is recommended:—

"At the end of the day, or period for which the sampling is to be carried on, the heap of fuel obtained for sampling purposes, as described above, is transferred to a sampling plate, and the larger lumps are all crushed down to walnut size. Should no sampling plate be available, four of the iron plates used for covering manholes and boiler flues may be utilised to obtain a hard, clean surface on the floor of the boiler house, and the crushing down of the sample may be carried out on these plates, with any heavy and flat lump of iron at hand.

"The heap of fuel, after this first crushing, is thoroughly mixed by turning over and over with a spade. It is then flattened down, two lines are made across it at right angles with the edge of the spade, and two of the four opposite sections are selected to form the reduced sample. The lumps in this are again crushed, the sample is again mixed, and the quartering operation repeated, until about 8 or 10 lbs. of fuel only remain, with no lumps that will not pass through a $\frac{1}{4}$-inch sieve. Two 2 lb. tins, with patent lids, are filled from this remaining heap of fuel, after thoroughly mixing the same with the hands or with a small shovel."

Pope, in the bulletin already quoted, suggests the following scheme of crushing for samples treated by hand:—

Weight of Sample to be divided.	Size to which Coal and Impurities should be broken before each Division.
1,000 lbs. or more	1 inch.
500 ,,	$\frac{3}{4}$,,
250 ,,	$\frac{1}{2}$,,
125 ,,	$\frac{3}{8}$,,
60 ,,	$\frac{1}{4}$,,

As regards mechanical crushers, the small crushing mill illustrated in Fig. 40, for samples containing lumps up to 2 inches cube, is quite satisfactory. It can be operated either by hand or electricity and crushes to a fineness of $\frac{1}{16}$ inch.

This mill, however, is not adapted for crushing samples of more than 28 lbs. weight, or for dealing with samples of fuel containing much bone or slate; coke also is sometimes very hard and difficult to crush in a small mill. For large samples of this kind it is necessary to have recourse to the use of a more strongly-built crusher, and that illustrated in Fig. 41, which is a combined crushing and sampling mill, is recommended for the work.

The fuel is fed into the hopper in 3-inch pieces or finer. It is first nipped by the top crushing members and is subjected to gradual reduction until discharged at the periphery below. A sample spout is placed opposite the discharge opening and is arranged to remove a certain percentage of the product, 5, 10 or 15 as the case demands. The sample thus secured is exactly representative of the whole, including the slate, sulphur, or other impurities.

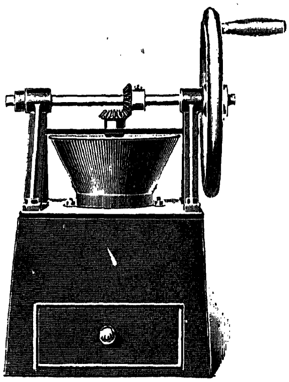


Fig. 40.—Small Grinding Mill for Coal Samples.

As the illustration shows, the machine is simple, massive and compact, and is strong enough to crush all the impurities that occur in fuel. The machine runs at a slow speed without vibration on any floor, and can be instantly adjusted for fine or coarse work while in operation, by simply turning the handwheel. It may be set as fine as $\frac{1}{4}$ inch or as coarse as $\frac{3}{4}$ inch, and delivers a uniform product.

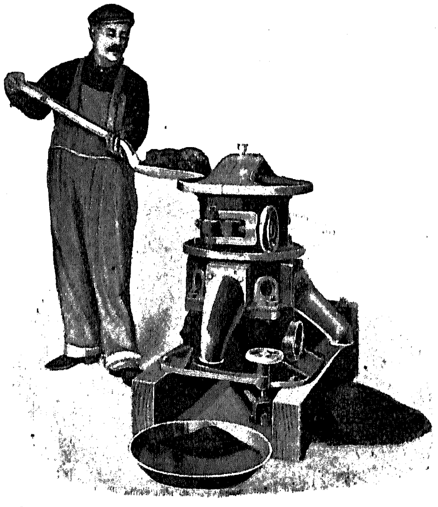


Fig. 41.—Sturtevant Grinding Mill for Coal Samples.

The final sample of fuel after the operations described above should amount to about 8 lbs. in weight and must contain no lumps that will not pass through à $\frac{1}{4}$-inch mesh sieve. It is well mixed with a small shovel or scoop, and three 2-lb. tins with patent lids are then filled from it. These form the laboratory samples and must be kept in a cool place until opened for examination and test. Each sample tin should bear a label giving full particulars of the date of sampling, the origin of the fuel and any other information regarding it that may be necessary for proper identification. In cases where a large number of samples are being dealt with at the same time, considerable care is necessary to prevent confusion of the samples, and the use of written labels is all the more urgent. For testing purposes, the samples may be marked simply A, B, C, etc., if the original sample tins bear corresponding letters in addition to the full details as to the fuel and date of sampling.

FURTHER REDUCTION OF THE SAMPLES IN THE LABORATORY.

The 2-lb. samples of fuel when opened in the laboratory are first passed through a $\frac{1}{12}$-inch mesh sieve, and the portion of the sample that remains on this sieve is ground down to a finer state of subdivision by aid of a No. 3 Kenrick mill, shown in Fig. 42.

If the fuel be very wet, or if the sample contains many pieces of shale, this more direct method of preparing the sample must be modified to meet the circumstances. The excessive moisture can be removed by spreading out the whole of the sample on three or four thicknesses of newspaper and by leaving it exposed to the air for several hours in a warm corner of the laboratory. Very wet samples should have the uppermost sheet of the paper removed two or three times, as newspaper is very absorbent and takes up much of the moisture from the fuel. It is also well to mix and turn over the fuel several times during this air-drying.

As regards the larger hard lumps of shale in the 2-lb. sample, these should be picked out and crushed in the steel mortar used for the final grinding of the fuel sample, since if these lumps are very hard they may break the grinding teeth of the mill or become jammed in it. Care must be taken that none of the pieces of shale are lost during the breaking down in the steel mortar, for shale possesses little heating value, and the proportion of it present in the final sample has considerable influence upon the heat value of the fuel. For this reason, the steel mortar and grinding mill should be covered with a perforated card when crushing shale, as the harder the lumps the greater is the tendency for the pieces to jump out and become lost.

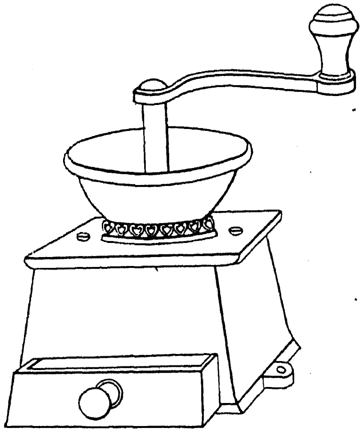


FIG. 42.—Kenrick Mill for preparing Laboratory Sample.

After the preliminary crushing in the mortar, the whole of the shale must be passed through the Kenrick mill, and the ground material be added to the general body of the sample, which will now occupy double the volume of the original sample and resemble a heap of coarse black gunpowder.

The sample is thoroughly mixed by transferring it to a funnel-shaped tin vessel with the outlet stopped by a cork, as shown in Fig. 43. As the coal is run through this on to a sheet of paper, the funnel is slowly moved around so as to distribute the sample equally on all sides of the pile. The heap is then flattened out and quartered as already described, and another mixing of the two quarters selected to form the reduced sample is carried out with the aid of the mixing funnel, in the manner described above. This operation is repeated again and again, until only about ¼ lb. of fuel remains. This is divided into two equal portions, one of these being used for the tests and the other reserved in a stoppered bottle until the tests are completed, in case of any mishap or mistake in the examination of the first portion of the sample.

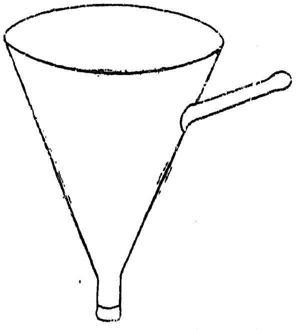


FIG. 43.—Mixing Funnel.

The final outcome is, two small portions of the fuel in a finely divided state, which are quite representative of the whole bulk, be it 10, 20, 50 or 100 tons. By a further grinding and reduction of one of these samples a small portion of fuel, weighing only one or two grams, can be obtained which will still be thoroughly representative of the original delivery of fuel.

The methods of sampling described above relate to solid fuels of a hard stone-like character, and these methods require modification when applied to the preparation of samples of lignite, peat, wood, and other similar fuels.

In these cases, when the fuel cannot be broken down by a crushing-mill of the type shown above, it is best to prepare the sample with the aid of a coarse joiner's saw ; the "saw-dust" obtained then forming a fairly representative sample of all the blocks of fuel which are sawn through in the course of preparing the same. Another method of obtaining samples of peat, wood, and lignite is to bore holes in the blocks with a joiner's auger or brace-and-bit, and to collect the fragments of material that come out of the holes—but sawing the blocks gives a more representative sample. It must be remembered, however, that the friction of sawing generates heat, and that the saw-dust obtained as sample will be drier than the original block from which it is obtained. In cases where the percentage of moisture is important, therefore, the determination must be carried out upon fragments of the original sample, and not upon the saw-dust.

The sampling of liquid fuels is best carried out in the tank or other vessel in which they are stored for use. The contents should be thoroughly mixed by blowing air through them, or with a large wooden plunger, and an iron or glass tube of ½ inch or ¾ inch bore, open at both ends, should be employed for collecting the sample. When the tube is lowered slowly into the tank until it touches the bottom and the upper end is closed with a rubber cork or with the thumb, a fair average sample of the whole depth of liquid is obtained. If preferred, the sampling-tube can be closed before it is lowered, and equal portions of the liquid can then be collected from different levels of the tank by withdrawing the stopper when the tube has been lowered to the required depth.

This method of sampling is quite satisfactory for the ordinary fuel-oils like creosote, but is not so applicable to the sampling of tar and pitch and in these cases a really fair average sample can only be obtained by collecting equal portions of the liquid as it is being run off *hot* from the still or stills in which it is prepared. If tar be sampled on delivery, a portion ought to be taken from each vessel as it is emptied into the storage tank, for it is difficult to mix large quantities of cold tar in a tank by the methods that are satisfactory for less viscous fuels.

Pitch, when it has attained the solid state, is an even more difficult fuel to sample, for, although easily broken into smaller pieces when quite cold, it cannot be ground in the ordinary mill, and the dust from dry pitch is highly dangerous, and produces a disease known as "*pitch-cancer*."

Pitch, therefore, should always be sampled when hot, and in the liquid state, if this is practicable.

THE LABORATORY EXAMINATION.

All fuel contains carbon, oxygen, hydrogen and nitrogen, with sulphur and certain incombustible mineral matters, such as iron-oxide, lime and magnesia. These latter on combustion of the fuel combine with the sulphur to produce their respective sulphates, and form the ash. Moisture is also present, even in mine samples of fuel, chiefly, however, as a mechanically held impurity.

The chemical examination of a coal sample may therefore cover the determination of the percentages of the elements and compounds above enumerated, in which case the analysis is said to be an "elementary" one; or it may cover the determination of the percentages of the products formed when coal is heated either in a closed crucible or in the presence of air. In the latter case, the analysis is said to be an "approximate" one.

For the purposes of the purchaser of the fuel, the approximate analysis is much the more useful, since it indicates what proportion of the fuel will escape as a gas when it is first heated, what proportion will remain as coke on the bars of the grate, and, finally, what percentage of the total fuel is a mere impurity in the shape of ash. When the figures for the actual heating value of the fuel; as determined by a reliable calorimeter, are added to the results of the approximate analysis, the engineer is provided with all the information he can require concerning the character and value of the fuel.

If the 2-lb. sample has been crushed and reduced to small bulk within 30 minutes, without recourse to air-drying, the moisture can be determined quite easily by heating 10 grams of the reduced sample in a copper or aluminium air bath at 230° F. (110° C.) for two hours. The loss of weight undergone by the sample in this time, multiplied by 10, gives the percentage of moisture in the original sample, and therefore approximately in the whole bulk of the fuel. A desiccator must be employed for cooling the sample before weighing, as perfectly dry, finely divided fuel absorbs moisture from the air and gains in weight, even while being weighed on the balance. It saves time, however, if the crucible be allowed to go nearly cold in the air with the lid on, before being placed in the desiccator. On no account must the crucible be placed on the balance pan and weighed while still hot, as this will show an increased weight. The crucible must be covered during its heating in the air bath, and the lid should not be removed while weighing.

In those cases where it has been impossible to carry to completion the repeated crushings and reductions of the sample, owing to the wet state of the fuel, the sample is reduced as far as practicable by hand crushing upon iron plates, and a rough sample of 50 to 100 grams, according to the bulk of the original, is dried by heating in the air bath for four hours at 110° C. The loss in weight of 100 grams of fuel gives the percentage direct, but the results will not be so accurate as those obtained from the smaller sample, owing to the fact that wet or damp fuel cannot be thoroughly mixed. For this reason, moisture contents above 6 per cent. are always somewhat unreliable, and if any limit is placed upon the moisture permitted in the deliveries, due allowance must be made for this error.

On the other hand, in hot weather, the coal is losing moisture during the whole sampling and crushing operation, and if this covers a long period of time, the final sample will contain 2 or 3 per cent. less moisture than the coal as delivered.

In those cases, therefore, where the contract arranges for fines to be imposed for excessive moisture, it is necessary to have a special sample taken, and rapidly crushed for the purpose of the moisture determination.

THE APPROXIMATE ANALYSIS OF FUELS.

The further tests of the fuel that will now be dealt with embrace the tests for ash, volatile matter, coke, and fixed carbon. All these tests are carried out with the 10-gram sample of fuel used for the moisture test, after this has been weighed and the loss on drying determined.

The whole of this 10-gram sample is first reduced to a very fine state by grinding it in a steel mortar and by repeatedly passing the ground sample through a 60-mesh sieve, until nothing remains on the sieve. This operation demands much time and patience when very hard fuels or those containing much slate and scale are being dealt with. On no account, however, must the work be shortened by rejecting the lumps and particles that are hardest to grind; for, as a rule, these are the least valuable portions of the sample and have the most effect upon the ash and calorimeter tests. As stated in the introductory part of this chapter, correct sampling is the basis of correct testing; and if the sampling be badly or carelessly performed, the whole of the test results are vitiated. The time spent in preparing the sample must not be curtailed, therefore, by omitting to observe any of the rules or precautions given above.

THE ASH TEST.

The finely ground sample is well mixed with a large spatula on a glazed sheet of paper and is re-dried in the air bath at 230° F. for half an hour, in order to expel the moisture taken up during the final grinding operation.

The ash test is made by heating 2 grams of this sample in a No. 00 size porcelain basin, over a Bunsen-burner flame, until all the hydrocarbon gases are driven off and the fixed carbon that remains is completely burnt away. The heating should be carried out very gradually, in order to give the hydrocarbon gases opportunity to escape without caking the coal; for if the coal cakes and a hard lump of coke forms, the combustion of the fixed carbon will prove a very lengthy process. If the preliminary heating has been sufficiently slow, however, the particles of coal will remain quite detached one from the other, and the burning-off of the fixed carbon can be completed in half an hour. The heating should be continued until no black specks of unburned carbonaceous matter are visible in the gray or reddish coloured ash.

In order to obtain more rapid combustion of the fixed carbon, it is well to support the basin upon an asbestos board, cut to fit it, and to tilt the tripod stand upon which this asbestos board is placed. The CO_2 and other gases produced by the Bunsen burner then pass away without interfering with the supply of air to the fuel in the basin, and the combustion of the fixed carbon will occur more rapidly. When the process of burning-off is quite finished the basin and its contents are allowed to cool, and the weight of the latter multiplied by 50 gives the percentage of ash in the dry fuel. An average fuel will contain 5 to 8 per cent. of ash. Washed (or picked) samples of good coal will contain as low as 3 per cent. of ash, while poor fuels and dirty slacks contain up to 16 and 20 per cent. of ash. In order to find the percentage of ash in the wet fuel, the results are multiplied by a factor denoting the percentage of dry fuel in the coal as delivered. For example, if the fuel contains 10 per cent. of moisture, every 10 tons as delivered will contain 100

— 10 = 90 tons of dry fuel, and the factor for conversion of the ash test will be 0·9.

VOLATILE MATTER, COKE, AND FIXED CARBON.

Volatile matter, coke, and fixed carbon tests are all carried out by heating 1 gram of the finely ground sample in a closed platinum crucible until all the hydrocarbon gases are expelled, and then weighing the residue. The test is thus a simple and expeditious one. Several precautions, however, must be observed in order to obtain reliable and concordant results, and the test must always be carried out under the same conditions as regards the size of crucible, the gas pressure and the height of flame used.

The crucible should be 1·4 inches high and 1·1 inches in diameter, and should be provided with a very close-fitting cover. It must be supported on a platinum-wire triangle made by twisting together three pieces of thick platinum wire, and by mounting these in the centre of an ordinary clay pipe-stem triangle. This enables the flame to play all around the crucible and prevents any access of air to its contents during the heating. The Bunsen burner must produce a flame at least 7 inches high under the normal conditions of gas supply, and the crucible must be supported on the tripod in such a way that its bottom is not more than 1½ inches above the top of the burner. A circular screen must be arranged round the burner and tripod stand to prevent side draughts, and it is well to carry out the test under a draught hood, since much smoke and soot are produced when bituminous fuels are being dealt with.

Having prepared this apparatus and made a trial heat of the empty crucible in order to see that it is completely enveloped in the flame, and that no air has access to its cover, the 1 gram of dry, finely ground fuel is carefully weighed into the crucible, and, the cover being placed in position, the heating is started with the full pressure of gas. The crucible will attain a red heat in about half a minute, and the evolution of the hydrocarbon gases, which escape and burn around the lid of the crucible, will commence immediately after this.

As a rule, the evolution of these gases lasts 1 to $1\frac{1}{2}$ minutes, and the character of the flame and time during which the gases escape enable one roughly to class the fuel as bituminous, semibituminous or anthracitic. When the last luminous "candle" has disappeared from above the lid, and the transparent flame of the Bunsen burner is seen once again, the gas is turned off, the crucible allowed to cool, and at once weighed, in order to determine the loss of weight. Since 1 gram of fuel was used for the test, the loss of weight multiplied by 100 gives the percentage of volatile matter contained in the dry fuel, while the weight of the button of coke multiplied by 100 gives the percentage of coke.

When testing highly bituminous fuels containing 30 to 40 per cent. of volatile matter, a thick deposit of soot will be found on the under side of the crucible cover, and also a thick deposit of flaky graphite on the inside walls of the crucible, due to the decomposition of the hydrocarbon gases at a red heat, in the absence of oxygen. The weight of these combined deposits amounts in these cases to about 15 milligrams, or to 1·5 per cent. on the test. Should it be thought wise to make corrections for these deposits, the following method may be used.

The soot can be removed easily before weighing the crucible by first wiping the inner side of the cover with cotton wool and then raising it to a red heat in the tip of a Bunsen-burner flame. The crucible containing the coke button must be kept covered by another closely fitting lid in the desiccator while this cleaning of the soot-covered lid is carried out. It is more difficult to allow for the graphite. If the crucible be inverted and tapped gently after the final weighing, the button of coke at the bottom will become detached and fall out, while the graphite will adhere to the walls of the crucible. Any particles of coke that remain on the bottom of the crucible can be detached easily with a spatula or forceps, and on re-weighing the crucible, with only the graphite inside, one obtains the correction necessary for the weight of the latter.

As a general rule this amounts to between 6 and 9 milligrams. It is deducted from the coke and added on to the volatile matter; for this graphite, it must be remembered, has been formed by the decomposition of portions of the escaping hydrocarbon gases at a red heat.

A lead counterpoise, which just balances the platinum crucible and lid, facilitates the rapid weighing of the crucible and its contents for the coke test, since the weights used then represent directly the weight of coke and graphite in the empty crucible. From these the percentages of volatile matter and fixed carbon are easily calculated.

The exterior of the platinum crucible used must be kept bright and clean by rubbing with wet sea sand after each test, and frequent adjustment of the lead counterpoise will be necessary in order to allow for the slight loss of weight that results from this cleaning.

As an example of the figures obtained in the coke test the following may be given, it being assumed that a lead counterpoise has been used to balance the crucible and lid and that the soot has been removed from the crucible lid in the manner described.

	Grams.
Weight of fuel used	1·000
Weight of button of coke and graphite left in crucible.	0·707
Weight of graphite alone	0·009

The graphite represents decomposed hydrocarbon gases, so 0·009 is deducted from 0·707, and one obtains 0·698 as the correct weight of the button of coke. Multiplied by 100, this gives 69·80 per cent. for the coke test and (deducting 69·8 from 100) 30·20 per cent. for the volatile-matter test of this fuel.

The fixed-carbon percentage is also obtained from these same figures by deducting from the coke percentage the percentage of ash found in the earlier test. Assuming that in this case the ash was 15 per cent., we have (69·80 — 15) 54·80 per cent. for the fixed carbon.

These results are all on the dry fuel sample, and if the tests are required for the fuel as delivered, the method of correcting by a factor, as already described under the ash test, is employed.

This completes the approximate analysis of the fuel, and, as shown, when once the sampling operations have been properly performed and a finely ground sample of the dried fuel is available, these tests can be carried out in from 1½ to 2 hours ; for while the carbon of the 2-gram sample is being burnt away for the ash test, the coke test can be proceeded with and finished.

It must be understood that the coke and volatile matter tests are what chemists term "empirical" tests—that is, they represent not original or permanent constituents of the coal, but decomposition products, obtained when the coal is heated—therefore the results will vary with the temperature attained and with the time for which the heating is continued. Unless, therefore, the test is carried out each time under exactly similar conditions, concordant results cannot be expected.

CHAPTER X

CALORIMETRIC TESTS FOR SOLID, LIQUID AND GASEOUS FUELS

THE laboratory determination of the calorific, or heating, value of a fuel is carried out by burning a weighed amount of the dried sample in oxygen in a vessel immersed in water, and by noting the increase of temperature of the latter resulting from the heat generated by the combustion. If the weight of the water by which the sample is surrounded be known, and if the whole of the heat be abstracted from the gaseous products of combustion, the rise in temperature of the water, multiplied by its weight, gives the number of heat units developed by the burning of the fuel. Two sets of units are in use—the British thermal unit, or B.Th.U., which represents the heat required to raise 1 lb. of water through 1° F.; and the calorie, or metric unit, which represents the heat necessary to raise 1 gram of water through 1° C.

If large quantities of fuel be employed in these determinations, the heat losses due to the size of the apparatus required, and to radiation, are proportionally high and difficult to allow for. The chemist surmounts this difficulty by taking great care in the preparation of the sample used for the calorimetric determination and by working with a comparatively small amount of fuel. The general practice is to use only 1 gram of fuel for the calorimeter test, and special precautions are therefore necessary to obtain the required degree of accuracy in the weighing and temperature measurements. Some chemists prefer to work with only one-half this amount, and, in this case, the rise in temperature of the water is usually less than 1° C. and all corrections for radiation losses can be dispensed with. Very accurate and standardised thermometers, which can be read to $\frac{1}{100}$th of one degree, are needed, however, when working with such small amounts of fuel.

Oxygen is used for the combustion, although air would be more in accordance with the conditions of practical work. The difficulties of igniting and burning a coal sample in a current of air, in a confined space, without smoke and soot production, are so great, however, that oxygen has been generally accepted as the only possible substitute.

Two methods of its application are in use. Either the fuel sample is burned under normal atmospheric pressure in a calorimeter of the "submerged bell" type, or the fuel is burned under high pressure in the "bomb" type of calorimeter. In skilled hands either method gives reliable and concordant results, but since the decomposition products of coal vary in character with the temperature, the calorific values obtained by the bomb are higher than those obtained by the bell.

When using either the bomb or the bell type of calorimeter, it is essential to have some protection against temperature exchanges between the vessel holding the measured volume of water and the outside air. Fig. 47 shows the form used. An outer water-jacketed vessel containing a stirrer encloses an inner air space, in which the nickel-plated highly polished vessel containing the water is supported on three small heat-insulating corks. When in position, the nickel vessel is thus surrounded by an air jacket and a water jacket, and if a round asbestos board or plate with the necessary openings in it for the thermometer, electrical ignition wires and oxygen supply tube be employed to close the top of the vessel, the temperature exchanges with the outside air will be reduced to a minimum. Fig. 47 also shows the mechanical stirrer used at the end of the test to obtain a thorough mixture of the water in the inner vessel. Electrical ignition is requisite with both types of calorimeter.

A small briquette-or tabloid-mould completes the apparatus required for fuel calorimetric work, since if it be attempted to burn the fuel in powdered form, it will be found that low results are obtained. This deficiency is due to portions of the fuel being blown on to the metal base of the bell when the ignition starts, and also to the ash which forms above and covers the lower layers of fuel as the combustion approaches completion. This necessity for pressing the fuel into small pellets or briquettes extends also to bomb tests, since, if the fuel be in powdered form, some portion of it is thrown against the internal walls of the bomb by the force of the explosion, and there escapes combustion.

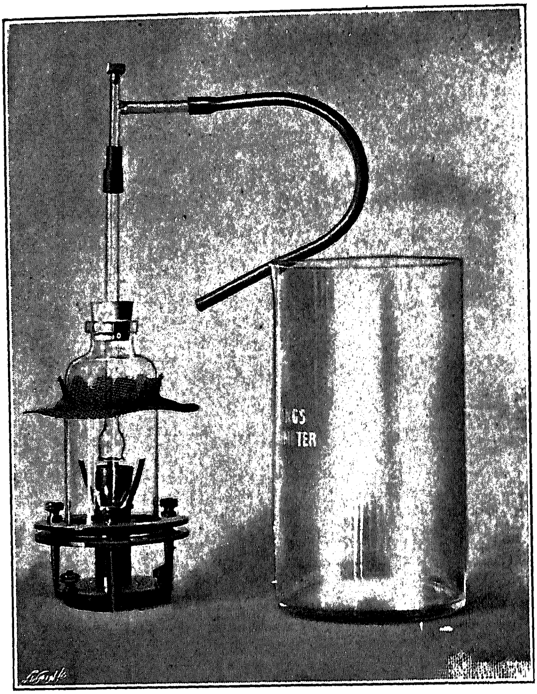


FIG. 44.—The Darling type of Calorimeter.

Bituminous fuels as a rule will form pellets, or briquettes, by pressure alone. In cases where sufficient tarry matter is not present in the natural fuel, just sufficient of a 1 per cent. solution of gum arabic to make the particles of fuel adhesive may be employed as "binder." For half a gram of fuel, three small drops of such a solution are sufficient. The pellets, or briquettes, must be heated in the air bath at

230° F. (110° C.) at least four hours to expel the last traces of moisture thus introduced before testing in the calorimeter.

Two standard forms of the "bell" and "bomb" types of calorimeter will now be described, but it must be understood that many different makes of these two types are in general use, and that practically all accurate calorimeters belong to one type or the other. Since accuracy in calorimetric work can be obtained only by attention to small details which cannot be given in this chapter, readers who wish to make themselves competent in this branch of fuel-valuation are referred to the handbook named below for more complete and detailed information on the subject.[1]

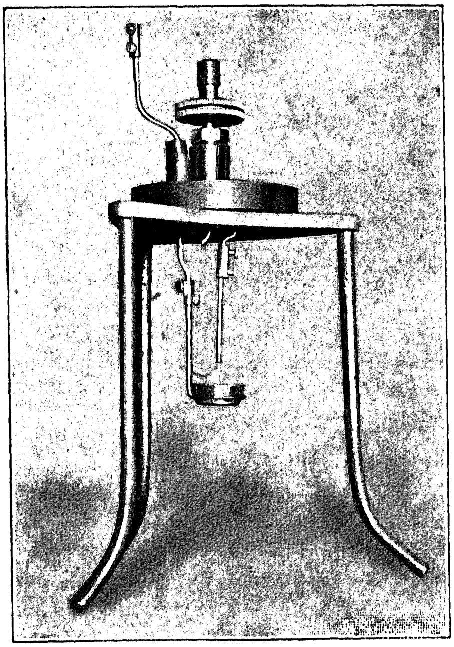


FIG. 45.—The Mahler-Donkin Bomb Cover and Holder for the Fuel Sample.

The Darling bell form of calorimeter is illustrated in Fig. 44, and consists of a glass bell jar closed above by a rubber cork and provided with a glass flange below, ground quite level on its lower side. By the aid of rubber rings, a circular brass ring and small milled screws and nuts, the glass bell can be firmly fastened down upon a brass support, through small holes in the baseplate of which the gases produced by the combustion of the fuel have to pass before they can escape and bubble up through the water. In order to break up the bubbles more completely, a piece of brass gauze may be fixed on the bell as shown, or better still, a copper spiral may be fixed above the brass base, and all the gases produced by the combustion forced to pass up this spiral before they escape through the water. One of these copper spirals will be found of great service in extracting the last traces of heat from the waste gases in all calorimeter work. A brass tube for leading in the oxygen, and two copper conducting wires for ignition purposes, pass through the rubber cork of the bell jar.

---

[1] "Fuel, Water and Gas Analysis for Steam Users," by J. B. C. Kershaw. Constable & Co., London. 2nd Revised and Enlarged Edition, 1920.

The Mahler-Donkin bomb calorimeter is shown in Figs. 45 and 46. It consists of a massive gun-metal cylinder provided with three projecting screwed stud-pins for bolting down the cover. This is shown in Fig. 45 supported on a laboratory tripod stand. The cover is provided with a milled-head screw valve for regulating the inlet of oxygen to the cavity inside the bomb. It also possesses an insulated conducting wire, which runs through the cover and terminates above the brass wire ring used for supporting the small platinum capsule, or crucible, containing the fuel. Thin lead wire is used to make a tight joint between the bomb proper and its cover, a circular groove in the cylinder top having as its counterpart a projecting ring on the underside of the cover.

The bomb is tested up to 1,800 lbs. pressure before it is sent out and is plated inside with gold in order to withstand the action of the nitric and sulphuric acids produced by the combustion of the fuel. Fig. 46 shows the bomb with the connection completed to the ignition apparatus, and ready for firing the charge. Twenty to twenty-five atmospheres is the usual pressure used in these tests—that is, 300 to 375 lbs.

It is advisable, therefore, to have a small back-pressure valve inserted in the milled-head screw in the bomb cover, in order to avoid a great loss of gas when disconnecting the oxygen-supply pipe and gauge from the bomb, after filling the same with oxygen.

At this pressure the combustion of the coal is practically instantaneous, and the thin platinum wire used for ignition purposes will generally be found fused, owing to the high temperature momentarily attained. In order to protect the platinum capsule or crucible from the same effect, and from the action of the molten slag produced, it is necessary to line it with a thin asbestos board, cut and shaped to fit the crucible, or capsule. This board must be dried and

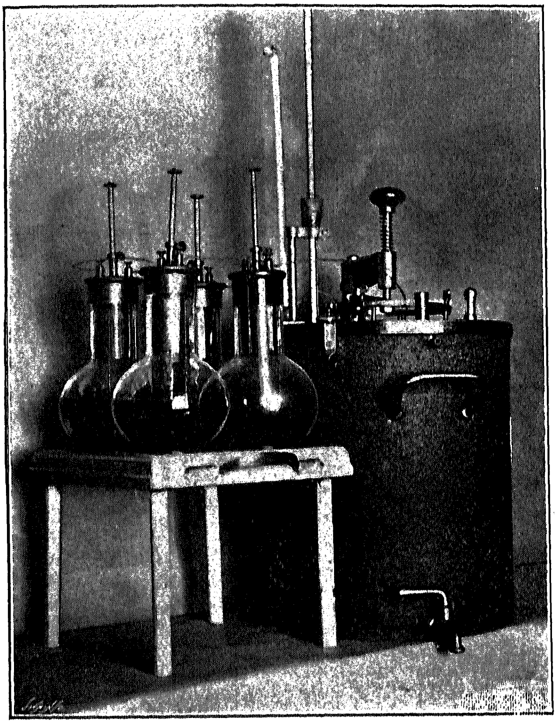


FIG. 46.—The Mahler-Donkin Bomb, and Containing Vessel ready for a test.

ignited before use in order to remove all matter that might vitiate the test results.

Further details of the method of operating the Mahler-Donkin and other bomb-type calorimeters, will be found in the handbook already referred to.

As regards the comparative advantages of the two types of calorimeter for regular routine fuel-testing work, the bell apparatus is less costly to set up and maintain in working condition, and the glass bell, if carefully used, will outlast two or three bombs with gold or enamelled linings. The only durable type of bomb is that with a platinum lining, and at the present price of platinum the cost of such a bomb is prohibitive. Further advantages of the bell type are that the combustion is visible, it being possible to observe its progress through small holes cut in the asbestos cover of the calorimeter, and that being carried out under only a slight *plus* pressure it is more in accordance with the conditions obtaining in practical work than the combustion in the bomb, which attains the violence and rapidity of an explosion. The rate of burning the briquettes or pellets in the bell can,

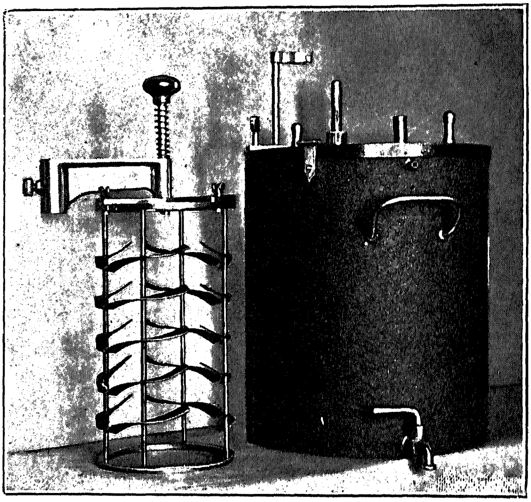


FIG. 47.—The Water Jacket and Stirrer for the Calorimeter Test.

in fact, be brought into exact ratio with the rate of combustion in the boiler furnace. A calorific value obtained under such conditions is of more practical value than one obtained by instantaneous combustion under 400 lbs. to 500 lbs. pressure, with the attainment of a temperature at which platinum melts. The decomposition products of coal vary considerably in composition with the temperature attained during their evolution, and it is reasonable to assume that the gaseous products evolved in the bomb under the conditions obtaining during a calorimeter test are quite different in composition and heat value from those evolved at much lower temperatures and under normal pressure. For scientific work the bomb is, no doubt, preferable to the bell; but for everyday use and for the practical requirements of boiler houses and large works the bell type has much in its favour.

LIQUID FUELS.

The methods used for determining the calorific value of liquids are similar to those employed for solid fuels. Liquid fuels, however, consist chiefly of rich hydrocarbons; the combustion must, therefore, be carried out under pressure in the bomb, for if it be attempted in the bell type of calorimeter soot is produced owing to imperfect combustion. In weighing and transferring the liquid fuel to the bomb, carriers consisting of small cylindrical blocks of pure cellulose are used, one of these blocks being able to absorb several times its own weight of any ordinary fuel oil. The saturated block, after being weighed, is burned under the conditions and with all the precautions necessary for solid fuel, the only difference being that a rather higher pressure is used, in order to obtain a greater supply of oxygen gas in the bomb. A blank test with the cellulose alone gives the necessary data for the calculations. As liquid fuels contain only traces of acid-forming elements, no trouble arises from corrosion, and a bomb provided with a gold lining will last for some hundreds of tests.

As regards the special precautions necessary to obtain correct results when testing liquid fuels, it must be pointed out that the absorbent cellulose blocks sold for this purpose absorb moisture as well as oil, and that it is necessary to dry them before use for one or two hours in the air bath at 212° F. When saturated with heavy oils of high boiling point they are also somewhat difficult to ignite, and it is advisable to place a little of the dry unsaturated cellulose in a loose condition around the platinum ignition coil of wire in order to avoid failure of the test from this cause. As the cellulose blocks are large in proportion to their weight and absorbent capacity, a larger platinum dish will be required than for the tests with solid fuel, and the platinum ignition wire should be arranged to hold down the cellulose block lest the explosive violence of the combustion blow it out of the dish.

GASEOUS FUELS.

The increasing extent to which gaseous fuels are now employed for purposes of power generation, either directly in internal combustion engines or indirectly under steam boilers, renders it useful to consider the laboratory methods by which such fuels can be tested and their heat value gauged.

The calorific value can of course be determined in the bomb calorimeter, but the difficulty of obtaining an accurately measured volume of the gas in the bomb without loss, and the very small volume that can be accommodated for each test, has led to the design and manufacture of special forms of gas calorimeters. These are all based on the same principle—namely, that of burning the gas in air under a steady and uniform pressure in some form of standard burner, and of absorbing the heat generated in a vessel through which a constant and uniform stream of water is flowing. They are thus "flow calorimeters," as opposed to the static condition obtaining in the calorimeters used for solid and liquid fuels.

The chief problems of their design and use are (1) to obtain the required uniformity in the flow of water and gas; and (2) to assure the absorption of the whole of the heat of the combustion gases. The thermometers used must be carefully calibrated, and most exact measurements of the water and gas employed are of course necessary in order to obtain reliable results. The standard of measurement for the calorific value of gases in this country is the British thermal unit, and the results are generally expressed as B.Th.U. per cubic foot of gas consumed. In countries where the metric system is adopted the results are usually expressed as calories per cubic metre, the large (kg.) calorie being employed in place of the small (gramme) calorie. To convert kg. calories per cubic metre into B.Th.U. per cubic foot it is necessary to multiply by 0·1123, while to convert B.Th.U. per cubic foot into kg. calories per cubic metre, the factor is inverted and becomes 8·898. The calculation of the calorific value of the gas is therefore made by multiplying the weight of water expressed in kg. (or lb.) flowing through the calorimeter in a given period of time by the rise in temperature expressed in degrees C. (or F.) and dividing the product obtained by the volume of gas burned in the same period of time, expressed in cubic metres (or in cubic feet). It is customary to measure the water in a graduated cylinder, but if great accuracy is required it is better to weigh it. In any case the gas volume as measured by a calibrated test-meter reading to the hundredth of a cubic foot, must be corrected to the standard temperature and pressure.

Several different forms of gas calorimeter have been designed and placed on the market, but two only will be described—the Jünker form and its latest modifications, and that designed specially by Professor Boys, to suit the needs of the London Gas Companies, when they first adopted the calorimetric standard for testing in 1909:

JUNKER CALORIMETER.

The earlier form of the Jünker gas calorimeter suffered from several disadvantages, but in its latest form, as now used in Germany and America, some of these defects have been remedied or modified. Apart from the gas meter and pressure regulator which are common accessories to all gas calorimeters, the apparatus consists of a tall cylindrical vessel of sheet copper, holding about 1,700 cc. of water. This vessel surrounds a combustion chamber within which an ordinary Bunsen burner is placed, and is connected by flexible tubing with the gas pressure regulator. The flow of gas should be regulated to yield about 1,200 calories of heat per hour, this being the best rate of absorption for the instrument. A throttle valve is placed on the waste gas discharge pipe of the calorimeter, and by means of this the amount of air passing into and through the instrument can be regulated. The water supply takes place through a tank, with an overflow, the height of which can be adjusted to give the head required. The main supply to this tank should be capable of providing up to three litres per minute, and the overflow pipe is so arranged that note can be taken at once if the flow through it ceases. The flexible tube which conveys the water away from the calorimeter, after abstraction of the heat of the combustion gases, is so connected that the water may be directed into the measuring vessel instantaneously without splashing or loss. A small measuring vessel is also provided for measuring the condensation water produced by the combustion of the hydrogen in the gas under examination. Two standardised thermometers are provided, graduated from 0° to 50° C. (each degree divided into tenths), for taking the temperature of the inlet and outlet water, and in the latest instruments these are arranged on the same level.

When taking readings with this instrument a position of equilibrium is allowed to set in, and after this stage is reached, the moment the pointer on the gas-measuring meter passes the vertical number on the dial, the water flowing from the outlet of the calorimeter is switched into the measuring vessel, and the amount collected during one or more revolutions of the meter pointer is recorded, together with the time. During this period, which may be from one to five minutes, the inlet and outlet thermometers are read at regular intervals and the average difference in temperature is used for calculating the test results.

BOYS' CALORIMETER.

Owing to the general adoption of gas for domestic heating and of the incandescent mantle for illuminating purposes, many of the leading gas companies and undertakings in the United Kingdom have obtained legal sanction during the last few years for the change from the photometric to the calorific standard of value, and the Boys' calorimeter is now adopted as the standard instrument for testing the quality of the gas supplied to the public in all large towns. The instrument consists essentially of an outer vessel of sheet brass, with a central chimney of thick sheet copper. Attached to the lid of this vessel is a brass box, which carries the outflow pipe and acts as an equalising chamber for the water flowing through the calorimeter. The lower or pendant portion of the box is kept cool by circulating water, and is connected at its lowest point by a union to six turns or spirals of copper pipe, similar to that used for motor-car radiators. A helix of copper wire is wound round this pipe and sweated on to it, in order to accelerate its action in absorbing the heat of the gases. A second pipe and helix of similar form surrounds the inner one, and is connected to it at the lower end by a union. This second spiral terminates at its upper end in a block, to which the inlet water-box and thermometer-holder are secured. Between the outer and inner coils which carry the water is placed a brattice made of thin sheet brass and filled with cork dust. This acts as a heat-insulator between the two coils. A cylindrical wall of thin sheet brass is secured to the lid, and serves to protect the coils of copper pipe, with their surrounding helices of wire, from injury, when these are removed from the calorimeter for cleaning purposes. The two thermometers for reading the water temperatures, and a third which may be added for reading the temperature of the outer air, are all near together and at the same level. The lid may be turned round into any position relative to the gas inlet and condensed water drip that may be convenient for observation, and the inlet and outlet water boxes may themselves be turned so that their branch tubes point in any direction. The instrument is convenient also in its small height, the thermometers being comfortably read when the instrument is standing on an ordinary table.

In order to prevent corrosion of the metal surfaces by the continued soaking action of very dilute sulphuric acid and dissolved oxygen, the whole of the coil system can be lifted up out of the vessel when the measurements have been made and placed in a jar containing a very dilute solution of carbonate of soda.

The water contents of the coil and equalising box of the Boys' instrument are only 300 cc., and of the vessel up to the overflow 400 cc. The designer justifies his inversion of the usual arrangement of small gas space and large water space by stating that the latter leads to irregular outlet temperature. In his opinion the gases should have sufficient space to pass slowly through the calorimeter, while the water should be taken rapidly through every channel strictly in series with the complete avoidance of parallel flow. The small water pipe used in his design, fortified with heat-collecting ribs or wires, carries sufficient water to absorb the whole of the heat present in the hot gases. Tests indicate that the form of construction yields variations only of ·01° or ·02° C., with a total rise of 24° C., and that in from ten to fifteen minutes after lighting up, the calorimeter is giving uniform readings.

CHAPTER XI

THE DESIGN AND MANAGEMENT OF FURNACES AND BOILERS FOR HIGH EFFICIENCIES

THE fundamental requirements of a good boiler are that it shall produce a maximum quantity of dry steam with the consumption of a minimum amount of fuel, and that it shall also possess some reserve of steaming power. For power plants which intend to make use of good lump or well-graded small coal, the choice lies between the large shell type of boiler, such as the Lancashire, the horizontal multitubular marine, and the large water-tube boiler.

The advantages of the former over the latter types are that its much larger water contents contain a big reserve of heat units, and that it can respond to a sudden demand for steam without much forcing or loss of pressure. It can also be used with a hard water supply, with less risk to the boiler than the water-tube type, since the cleaning of plates from scale is more easily carried out than the cleaning of partially stopped-up tubes.

The disadvantages of the Lancashire shell type of boiler are its water-cooled furnace, which sometimes leads to incomplete combustion and smoke production with highly bituminous fuels, and its poor circulation, which leads to a low steam-raising capacity for the volume of water contained. The former disadvantage can be overcome by the use of a preheated air supply and artificial draught, while the latter defect can be remedied by any of the well known devices for displacing the water from those pockets and corners where no movement occurs naturally. With these improvements in its method of working, the Lancashire type of boiler is one of the most reliable for use with ordinary well-screened slack or coal testing up to 12·5 or 15 per cent. ash.

It is quite a mistake to suppose that bituminous fuel testing up to 35 per cent. volatile matter cannot be burned in these boilers without excessive smoke production, for with proper regulation of the air supply and some arrangement for admitting secondary preheated air at the bridge or through the furnace door, during the period of maximum evolution of the hydrocarbon gases, high efficiencies and smokeless combustion are possible. There are many of these air-regulating devices on the market.

The Lancashire shell type of boiler, however, is not adapted for burning low-grade fuels with high ash contents, since these demand some form of brick-lined combustion chamber and mechanical ash-handling equipment for their satisfactory combustion. The comparatively restricted furnace and ash space of the Lancashire boiler is inadequate for these additions. When low-grade fuels, either in the dust or lump form, are to be burned, therefore, the large water-tube boiler must be adopted.

In large plants where the power demand is considerable and a battery of ten to twenty boilers is required, it is the wisest course to install boilers of each type, so that the plant, regarded as a whole, may possess the special advantages of each. The battery of Lancashire boilers would thus be fired with the better classes of fuel, either by hand or by mechanically operated stokers, and would be relied upon to provide the main steam supply and to take any bad feed water that came along. The water-tube boilers, on the other hand, would be operated with mechanical stokers and the poorer classes of fuel, and would provide steam for the periods of exceptional activity.

In very large plants a Bettington vertical tubular boiler[1] might also be included, in order to make use of the fine coal dust which collects on the floors and ledges of the mines. This would only require drying in order to yield a fuel of high calorific value, and its removal from underground would increase the safety of the operations. The dust from a large number of mines would be required, however, to keep one of these boilers in constant operation, and its installation is only suggested where the conditions warrant the expenditure.

---

[1] See Fig. 22, p. 78, for illustration of this boiler.

As regards the method of gasifying poor fuels, described in Chapter I., either type of boiler can be adapted for gas-firing, but the form of burner employed must be different in the two cases. A long conical luminous flame is required in the Lancashire type of boiler and a spreading non-luminous diffused flame in the water-tube boiler. The difference is due to the fact that in the former case the greater portion of the heat which is transferred to the water passes through the plates of the boiler, chiefly by direct radiation from the flame itself, while in the latter case the brickwork is the chief source of radiated heat. With suitable burners and baffling arrangements, however, high efficiencies, up to 70 per cent. and over, are attainable with gas-heating, and if the Boncourt system of flameless combustion be used, still higher efficiencies are possible.

THE DESIGN AND SETTING OF BOILERS.

The general conditions which must be observed in the design and setting of either type of boiler, if high efficiencies are to be obtained, are the following :

(*a*) The furnace grate and combustion chamber of the boiler must be adapted to the physical and chemical characteristics of the fuel to be burned, and the heated gases should not be allowed to come into contact with the water-cooled plates or tubes before perfect combustion has been attained.

(*b*) The plates or tubes which are in contact with the water on the one side and with the hot gases on the other should be of ample superficial area to raise the steam required under normal conditions from each boiler, without undue forcing of the fires, and the internal design should be such that the discovery of any corrosion or cracks may be made easy during the periodic inspections.

(*c*) All portions of the heating surfaces exposed to radiation or contact with the hot flame and gases should be constantly covered with water, and the accumulation of scale on these surfaces should never be allowed to exceed $\frac{1}{8}$ inch in thickness.

(*d*) The circulation of the water in boilers of the internally-fired Lancashire type should be promoted by some mechanical means at the dead points, notably underneath the ash boxes.

(*e*) The side and end flues of the boiler should be provided with mechanical scrapers, in order that flue dust may be regularly removed without interfering with the work of the boiler. Poor draught, especially when burning low-grade fuels, is often caused by the blocking of the flues with dust which ought never to have been allowed to accumulate. The poorer the fuel the more frequent should be the cleaning of the flues.

(*f*) In water-tube boilers the arrangement and number of the baffles have great effect upon the efficiency, and it is a mistake to assume that one fixed arrangement of the baffles is the best for all classes of fuel. The experiments of Henry Kreisinger and W. T. Ray upon "The Adaptation of Boiler Furnaces to Available Fuels" prove that there is great scope for improvement in this direction in the majority of existing water-tube boilers. This paper appeared in the *Journal of the Western Society of Engineers* for November, 1913.

(*g*) The outer brickwork of the boiler setting should be air-tight, since the infiltration of air into the flues through faulty bricks and cracked joints not only spoils the draft, but leads to large heat losses. It is well to build the outside walls with a 3-inch air space enclosed between the two thicknesses of brickwork, and to paint or tar the outer wall at frequent time intervals, in order to close all cracks and joints. In some cases sheets of asbestos or iron plate have been built into the wall for the purpose of rendering the brickwork air-tight. The boilers at the new Ashley St. Station, New York, described in *Power* for October 9th, 1917, are an example of good construction in this respect.

(*h*) The exposed portions of the boiler shell and main steam pipes should be covered with a thick layer of some good heat-insulating material, in order to reduce convection and radiation losses. The spongy substance obtained by blowing air through slag as it solidifies, and known as "silicated cotton" or "slag wool," is one of the best materials for this purpose. The heat lost by radiation from uncovered boilers, especially when they are unprotected from atmospheric influences, is far greater than is suspected.

The diagram, Fig. 48, shows that under normal good conditions nearly one-fourth, or 24 per cent., of the heat of the fuel consumed in boiler furnaces is lost either by radiation or with the waste gases. It is wise, therefore, to take all possible precautions when installing boilers to reduce these two items of loss to a minimum. The fuel saved by even a 5 per cent. reduction of these losses would speedily pay for the better material or skill put into this work.

The methods of checking and controlling the work of the boilers will be dealt with in Chapter XII., when the losses in the waste gases will be more closely examined. It may be stated here, however, that the three essentials required for good combustion and high efficiency in the burning of fuel are : (*a*) a sufficiency but not a great excess of air ; (*b*) a thorough admixture of this air with the volatile hydrocarbon gases produced when the fuel is heated ; (*c*) a temperature sufficiently high to cause the ignition and complete combustion of this hydrocarbon gas and air mixture.

The poor evaporative results obtained in many steam-boiler plants are due to the utter failure to maintain one or more of these three conditions of good combustion, and this failure is quite as often due to faulty design of the furnace and combustion chamber of the boiler as to want of skill on the part of the fireman.

Thus condition (*a*) demands mechanism or apparatus for controlling and regulating the air supply, condition (*b*) requires means for mixing the air and volatile hydrocarbons, and (*c*) necessitates the provision of combustion chambers in which the burning of the hydrocarbon gases can be completed before they come into contact with the water-cooled surfaces of the boiler. No fireman, however skilled, can obtain good results from boilers which are not provided with these requirements.

Considering, first, hand fired furnaces, these as usually planned and operated fail as regards conditions (*a*) and (*b*), for it is evident that the opening of the furnace door for charging fresh fuel, or for cleaning the fires, must allow large volumes of cold air to pass through the furnace, thus abstracting much heat from the fires and plates of the boiler, with no useful result. No hand fired boiler ought therefore to be started up without an automatic connection between the furnace doors and the dampers, so that when the firing door is opened the appropriate damper is closed (or nearly closed) and the draught through that particular furnace is cut off or considerably checked. The system known as the "balanced draught" system of working boilers attains this end by other means.

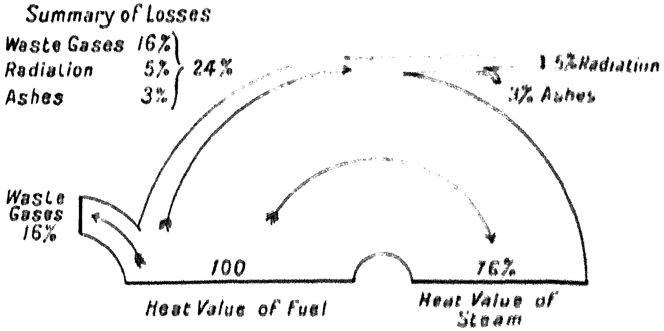


FIG. 48. Efficiency Diagram for a well managed Boiler Plant

Such an arrangement is simple to install and easily maintained in working order, yet one seldom finds hand-fired boilers provided with it.

Again, in hand fired furnaces there ought to be means provided for varying the air supply at different stages of the combustion process, for a furnace which has just received a charge of solid fuel and is filled with hydro-carbon gases demands more air than one which contains only glowing coke and cinders. As already stated, many forms of regulating devices have been brought out, but are seldom used; yet no hand-fired boiler ought to be allowed to work without one or another of these attachments.

The best types of furnace for hand-fired boilers are provided with closed ash pits; with the mechanical or automatic devices described above for regulating the air-supply; and with means for providing a controlled supply of preheated air at the bridge or end wall of the furnace, for use during the periods of maximum evolution of hydrocarbon gases. The length of each furnace should not exceed 6 feet or its width 3 feet, since this is the limit of size which one man can cover with fuel by aid of a shovel in a reasonable time.

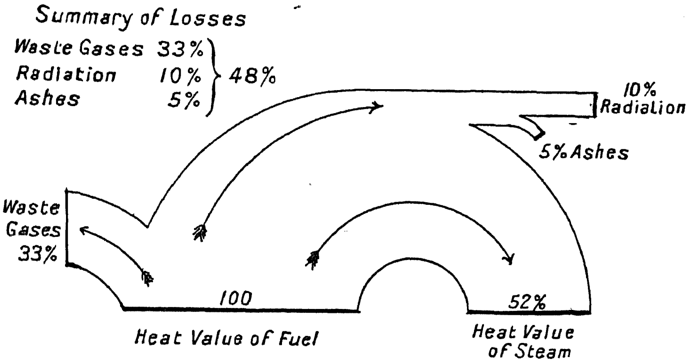


FIG. 49.—Efficiency Diagram for a badly-managed Boiler Plant.

AIR LEAKAGE SHOULD BE GUARDED AGAINST.

The corners of the grate on each side of the door should be fitted with nearly straight firebars giving very slight air apertures between them, since it is in these corners that much air leakage into the furnace may ordinarily occur, with bad effects upon the efficiency. The superficial grate area and depth of fuel bed must be adapted to the fuel burned. It is a mistake to assume that the conditions which suit one fuel are also the best for another of different composition and physical structure. The rate of combustion and depth of fuel bed which will give the best results under given conditions of draught can only be ascertained by actual trial. The average figures of 15 lb. of fuel per square foot of grate area per hour, with a fuel bed 8 inches thick and a draught equal to $\frac{1}{3}$ inch water gauge behind the fire, may be widely departed from in practice.

In small power plants a hand-fired boiler equipped as described above, and placed under the charge of a well-trained man, can show quite as high efficiencies as any type of mechanically operated furnace. It is only where larger boiler installations are concerned, or when low-grade fuels are to be burned, with the production of large amounts of clinker and ash, that mechanical stokers show any economic or other advantage.

Considering now the maintenance of the three essentials of good combustion in mechanically operated boiler furnaces, it is evident that with a regular and constant fuel feed, and no opening of the furnace doors for firing or cleaning purposes, the regulation and control of the air supply becomes much simplified. The maintenance of condition (*a*) of good combustion is therefore provided for in all the best-known types of mechanical stoker, but conditions (*b*) and (*c*) are not always observed, especially when burning fuels which evolve large amounts of combustible gases.

Brick-lined combustion chambers which store up heat, and assist by radiation in maintaining a high temperature in the furnace, are particularly useful in such cases. A large amount of heat is absorbed when these gases are being evolved from the freshly charged fuel, and unless this can be supplied from the furnace walls, the fires are damped down every time fresh fuel is spread over them.

On account of the restricted size of the furnaces and flues, the provision of refractory lined combustion chambers is not possible in the Lancashire type of boiler. In this respect it is at a disadvantage when compared with the water-tube and other boilers, possessing an independent furnace and grate. In many instances, however, the combustion chamber of these boilers (as originally planned and erected) could be enlarged with advantage, and the raising of the boiler shells and tubes on their supporting framework 18 to 24 inches has often led to a considerable increase in the efficiency of the boiler.

As regards the methods for attaining a thorough admixture of the air and volatile hydrocarbon gases in mechanically operated stoking appliances, steam-jets, hot-air jets, and "baffling" are the devices employed.

The use of steam-jets is the most popular, but unless carefully controlled these jets consume much more steam than is suspected, and lead also to excessive losses of heat in the chimney gases. Steam consumptions of from 4 to 8 per cent. of the total steam generated are quite common with these aids to more perfect combustion. The steam also has an erosive action on the jets, so that these are continually passing more steam than they were designed for.

A small pump to provide hot air, and arrangements for forcing this air under pressure into the combustion chamber at selected points, in order to produce whirling and eddying effects upon the burning gases, is the better method of aiding the chemical changes in the combustion chamber. If this plan be combined with the skilful use of "baffles," the efficiency of the furnace will be raised to its maximum point. As already stated, striking effects can be obtained in some cases by altering the number and arrangement of the baffles in water-tube boilers.

The best method of baffling, however, can only be found by actual trials with the selected fuel; and no one arrangement of the baffles will suit all classes of fuel.

Finally, it may be pointed out with respect to mechanically operated furnaces that it is a mistake to assume, as is often done, that when once the best rate of fuel feed and speed of travel of the fuel along the grate has been determined, for any particular grade of fuel, the boiler can be left in charge of common labourers or unskilled men. The lesson taught by experience is that mechanical stokers demand skilled supervision and management if they are to yield their highest results. The economic gain resulting from their use lies chiefly in the fact that one skilled operator can attend to double or treble the number of boilers he could attend to if these were hand-fired.

The labour costs are therefore considerably reduced, but this saving is often balanced by the interest charges on the capital represented by, and upkeep charges upon, the mechanical portions of the plant.

In those places and districts, therefore, where there are plenty of intelligent men available who can be trained to make good firemen, it is perhaps unwise to install mechanical stokers, unless the other circumstances of the case render their adoption desirable.

An adequate supply of air has been shown to be an essential requisite for good combustion. If this air can be heated before entering the boiler furnace or the combustion chamber, the temperature attained and efficiency of the steam-raising process will be considerably increased.

The usual method of obtaining the necessary supply of air to the furnace and combustion chamber in the past has been that of relying upon the chimney which carried away the products of combustion. Chimney draught has, however, never been entirely satisfactory, even when aided by the use of steam-jets ; and in modern boiler plants either forced or induced draught apparatus is installed.

The assumption that chimney or natural draught costs nothing is quite fallacious, for not only is the capital outlay upon a chimney 150 to 200 feet high considerable, but its efficiency for producing draught depends upon the heat of the gases which pass up. Thus to produce a suction equal to 1 inch on the water gauge at the base of a chimney 150 feet high, the temperature of the exit gases must be 600° F., and below this limit the draught will fall off considerably. But with the exit gases at 600° F., the heat lost will amount to between 17 and 33 per cent. of the fuel burned, the 33 per cent. loss corresponding to 6 per cent. CO_2 in the exit gases. The cost of chimney or natural draught with fuel at 15*s*. per ton, therefore, varies from 2*s*. 6½*d*. up to 4*s*. 11½*d* per ton of fuel consumed, over and above the interest and upkeep charges for the chimney.

Where new equipment is being installed, fan draught is in all cases the more economical and efficient; for not only can the fan be run at the speed best suited to the fuel being burned, but the draught can be altered according to the load on the boilers. With fans, also, the heat can be abstracted from the exit gases to the lowest possible limit without any fear of decreasing the draught, and the preheating of the air supply becomes a much more practicable and efficient proposition.

As regards the choice between the two systems of "forced" and "induced" draught, each method has its advantages, and the local conditions must be studied carefully in each case before deciding which to install. If the fan is placed behind the boilers at the foot of the chimney; that is, if the induced draught system be used, the heat losses by air leakage through the brickwork of the boilers and damper holes may be as high as with chimney draught, unless great care is taken to make the boiler and flue brickwork air-tight. For this reason, the "forced"-draught system is preferred by many engineers. In this case, if leakage occurs, the pressure is from within; and the smoke or flame that escapes from the crack calls attention to the loss at once.

As regards the draught required to burn ordinary lump coal or a well-screened slack, 0·33 inch on the water gauge should be registered behind the bridge wall of the boiler furnace and 0·45 inch in the main flue behind the boiler, with either natural or induced draught. It is advisable to be able to increase these pulls up to 0·50 and 0·70 inch respectively, when circumstances require it.

A fixed-draught gauge, with the face dial marked in tenths of an inch, ought to be attached to every boiler furnace, so that the firemen may be able to judge of the pull on the furnaces and state of their fires without opening the furnace doors. Similar draught gauges should also communicate with the main flues and the base of the chimney, in order that the engineer in charge may be kept informed as to the state of the draught on the whole steam-raising plant. With forced draught apparatus the need for gauges is just as urgent, but the places where they are installed must be altered to suit the system.

ADVANTAGES OF FAN-DRAUGHT.

The following extract from a paper on "Fuel Economy," read by the writer, in conjunction with W. H. Booth, before the Institution of Electrical Engineers in London, summarises the advantages of fan-draught :—

"Fan-draught must, therefore, be considered in the light of enabling an economy in chimney construction to be effected, and full use made of feed-heating apparatus. It is also useful as enabling boilers to be forced to rapid steam production, and presents itself as a safeguard against sudden load in lighting stations, and as a means of surmounting the load peak without excessive boiler plant. Fan-draught is thus useful as a means of reducing capital expenditure on chimneys and boilers, by promoting the rate of combustion of fuel at higher rates per unit of grate area. It enables the thickness of the fire to be regulated in better accordance with the fuel size and generally promotes elasticity. It is also useful in enabling the hot gases to be compelled to pass over all the heating surface, and baffles may be introduced that would otherwise be too great a hindrance. Its economy in other cases appears to demand the fullest practicable reduction of the calories in the exhaust gases by feed-water heaters, which in large stations may well be in two stages, and perhaps by air heaters for furnace supply."

The object of burning fuel under steam boilers is to produce "steam." The boiler itself, therefore, should be restricted as far as possible to this purpose, and it should not be used for purifying the water, or for preheating the water up to boiling temperature—both of which operations can be more efficiently carried out in other and specially designed forms of apparatus.

Fig. 50 shows, in the form of a diagram, the heat units absorbed in raising 1 lb. of solid steel and 1 lb. of water respectively from the absolute zero of temperature (—273° C. or —460° F.) up to 940° F. At 212° F. a great absorption of heat occurs in the case of water, without any corresponding rise in temperature ; and it is the great absorption of heat at this point which renders steam-raising different from many other processes of heat transfer. The vertical scale of the diagram represents the temperature in degrees Fahrenheit, while the horizontal scale represents the heat absorbed in British thermal units.

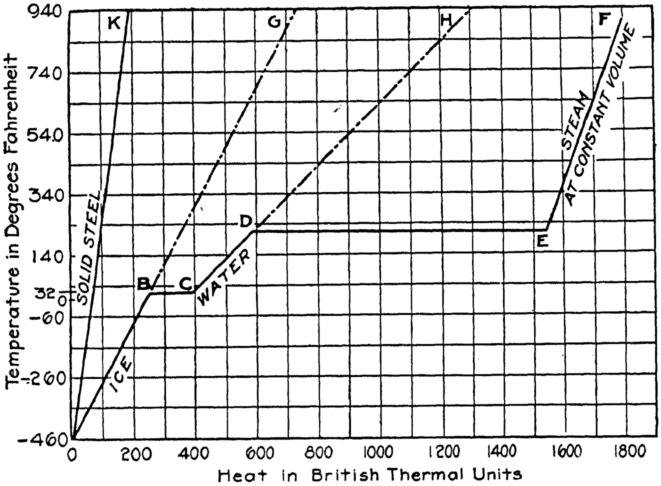


Fig. 50.—Heat Absorption during Conversion of Ice into Steam.

In the case of steel the heat absorption is indicated by a straight and continuous line (AK), and less than 200 heat units are required to raise the temperature from the absolute zero up to 940° F. The heat absorption curve for water, on the other hand, shows that nearly as many heat units are required to raise it from the melting point of ice up to its boiling point (indicated by the line CD), and that at this temperature there is the disappearance of 966 heat units (indicated by the horizontal line DE) before any further increase in temperature occurs. These heat units in fact represent the energy required to convert the 1 lb. of water at 212° F. into 1 lb. of steam at 212° F., and are called the "latent heat" of steam.

From this point onward the temperature of the steam increases faster than that of the water for a given number of heat units, since 250 B.Th.U. suffice to raise 1 lb. of steam from 212° F. to 940° F. (see line EF in diagram). The dotted lines BG and DH show the direction the heat absorption lines would have taken had there been no internal molecular work required when the ice changed into water, and the water into steam, at the points B and D respectively in the temperature curve of the diagram.

The lesson of this diagram is that 1,300 B.Th.U. are required to change 1 lb. of ice at 32° F. into steam at 600° F., or more than six times that required to raise 1 lb. of solid steel to the same temperature, and that had there been no change of state in the case of ice and water, this amount of heat would have produced a final temperature of over 2,600° F.

Conversely, the heat absorption of the water at this temperature, 212° F., is exceptionally great, and the rate of the transfer of heat through the boiler plates is at its maximum.

In order to obtain the highest efficiency from steam boilers, therefore—that is, the greatest rate of heat transfer—the boilers should be fed with water at or near the boiling point, and the preliminary heating of this water should take place in accessory apparatus, such as feed-water heaters and economisers, using low temperature and other forms of waste heat which are inapplicable for steam-raising purposes.

Working under these conditions, with clean boiler plates, there is a wide margin for obtaining much higher evaporative results from steam boilers than are at present customary, without any loss of efficiency, since the danger of overheating the plates or tubes under these conditions of work is almost negligible.

The following extract from Bulletin 18 of the Bureau of Mines ("The Transmission of Heat into Steam Boilers," by Henry Kreisinger and W. T. Ray) proves that this opinion is supported by the most advanced scientific workers on this subject in the United States :—

"The results of the investigations described in this report indicate that the conductivity of the heating plates of steam boilers is so high that the present steaming capacities can be tripled or quadrupled by forcing over the heating surfaces three or four times the weight of gases now passed over them. With well-designed mechanical-draught apparatus this greater weight of gases can be forced through the boilers at a small operating cost. It is possible to increase the capacity of many of the present boilers in this way without reducing their efficiency much ; in fact, by a proper arrangement of the heating surfaces, the efficiency can be made higher than the present rating. The efficiency of any boiler can be increased by arranging its heating surfaces in series with respect to the path of hot gases. New boilers of high efficiency can be constructed by making the cross-section of the gas passages small in comparison with the length."

Finally, the steam produced by the boiler should be superheated, in order to minimise the heat losses due to radiation during its passage through the steam pipes to the point where it is used, and also to insure that dry steam arrives in the engine cylinder or turbine drum, rather than a kind of Scotch mist, which too often has to do duty for steam in small power plants.

Limits of space will not permit the various types of feed-water heaters and economisers or superheaters to be discussed ; but no up-to-date steam-raising plant can afford to be without these essential accessories to economical steam production.

To summarise, however, what has been said—the production of steam from water should be carried out in several stages, beginning with the raising of the temperature of the purified feed water to 100° F. by aid of exhaust steam. This warm water is then passed through one or more series of economiser tubes worked on the counter-current principle, and heated by the waste gases from the boiler. If still below the boiler temperature, the last degrees of heat are added, either by the use of live steam or by passing the feed water through the control apparatus which protects the superheaters from the direct heat of the furnace. The water then enters the boiler at the critical temperature and is at once ready for the absorption of the latent heat which converts it into steam.

CHAPTER XII

THE CONTROL OF THE COMBUSTION PROCESS AND THE USE OF AUTOMATIC GAS-TESTING APPARATUS

THE waste gases passing away from boiler plants carry with them a large proportion (from one-third to one-fourth) of the heat of the original fuel, and if high efficiencies are to be attained for the whole power plant, it is imperative that the heat losses with these gases should be reduced to a minimum.

This reduction can be attained in three directions: (1) By cutting down the volume of the waste gases—that is, by working with a minimum excess of air. (2) By reducing the temperature of the gases by a skilful use of economisers and other forms of low-temperature heat-abstraction apparatus. (3) By substituting artificial for natural draught, and thus obviating the necessity of passing hot gases into the chimney shaft.

As regards the total amount of the heat losses through the exhaust steam and waste gases in a modern power plant, Fig. 51 is a diagram showing the whole of these losses. The large proportion of the heat which passes away in the waste gases and in the exhaust steam is at once apparent. In the case illustrated in Fig. 51, only 14·4 per cent. of the original heat value of the fuel is represented in the effective horse-power of the engines, over 80 per cent. of the heat energy of the fuel having been lost with the waste gases from the boilers and with the exhaust steam. As already stated the heat of the exhaust steam can be most satisfactorily recovered by using it for the preliminary heating of the feed water for the boilers, and with well-planned and well-managed apparatus over 90 per cent. of this heat can be reclaimed.

The problem of the recovery of the heat of the waste gases is not so simple, since it is not possible, owing to the impurities which they carry, to abstract their heat by direct contact with the water intended for the feed. The usual plan is to abstract the heat by the aid of economisers—that is, a series of pipes placed in a special chamber at the rear of the boilers, through which the gases pass on their way to the chimney. As usually operated, the economiser system is capable of much improvement. Not only is the counter-current system of operating the flow of water and hot gases usually ignored, but the economiser tubes are not kept sufficiently clean, either outside or inside, to yield their highest efficiency. The number of tubes also is never sufficiently great to abstract all the heat of the gases, for the temperature at which the gases are allowed to escape to the chimney is usually between 550 and 650° F., whereas with better equipment and management this might be reduced to 250° F. Below this point the moisture contained in the gases would condense on the economiser pipes and would cause trouble owing to its acid constituents. But in time it is possible that even this difficulty will be surmounted, and that the whole of the heat contained in the exit gases from the boilers may be utilised.

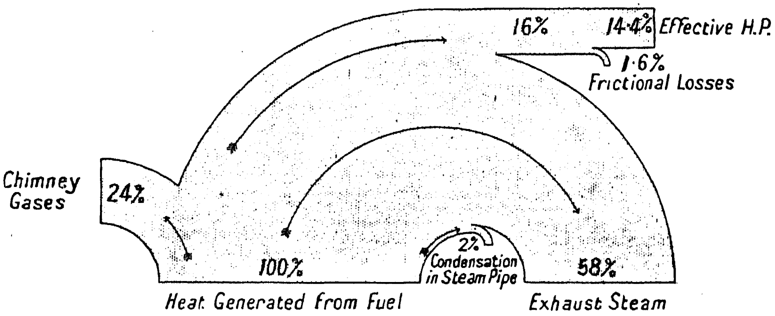


FIG. 51.—Efficiency Diagram for a Power Plant.

Table I. shows how rapidly the heat losses in the waste gases increase with their dilution, for while at 12 per cent. CO_2, and 600° F. the loss is 17·1 per cent., at 8 per cent. CO_2, and the same temperature, the loss is 25 per cent.; and at 5 per cent. CO_2, 39·3 per cent. of the total fuel used is lost.

TABLE I.—PERCENTAGES OF FUEL WASTED BY HEAT CARRIED AWAY BY EXIT GASES AT VARIOUS TEMPERATURES AND PERCENTAGES OF CO_2.

Temperature.	Percentages of CO_2.					
	4 per cent.	6 per cent.	8 per cent.	10 per cent.	12 per cent.	14 per cent.
400° F.	32·4	21·8	16·4	13·4	11·4	9·8
500° F.	40·5	27·3	20·8	16·8	14·2	12·3
600° F.	48·6	32·8	24·9	20·2	17·1	14·8

Adapted from Table III. in Appendix, "Smoke Prevention and Fuel Economy," by Booth and Kershaw.

Turning now to the consideration of the customary methods of controlling the heat losses of the waste gases, temperature and chemical tests ought to be carried out regularly by the engineer or chemist in charge of the steam-raising plant. The temperature of the waste gases ought to be noted and recorded at frequent intervals—(1) at the exit from each boiler into the main flue, (2) at the inlet and exit of the economisers, and (3) at the base of the chimney. Permanent and fixed thermometers may be placed at these points, or holes may be provided with 30-inch lengths of 1¾-inch wrought-iron pipe, the flanged top of which is kept closed with a tight-fitting wooden plug when it is not being used for making a test. Mercury thermometers filled with nitrogen are reliable for temperatures up to 1,000° F., but they must be mounted in a suitable carrier and must be left in the path of the flue gases long enough to attain the gas temperature—that is, ten or fifteen minutes, according to the thickness of the metal case surrounding the thermometer bulb.

The only point where the temperature of the gases may exceed the limit named above, as measurable by a mercury thermometer, is at the exit from each boiler into the main flue. But if the temperature here registers over 900° F., it means that the boiler is dirty and badly scaled, and the sooner it is put out of use the better for the efficiency of the plant. The following are the temperatures which should be maintained in a well-managed plant: Temperature at exit from boilers into main flue, 650° F.; temperature at exit from economisers, 350° F.; temperature at base of chimney, 300° F.

As already stated, with forced or induced draught the temperature of the gases that issue from the economisers may be reduced to the point at which condensation of the moisture commences to occur.

Concerning the chemical tests which are necessary to determine the air excess and air-leakage of the boilers, it is obvious that only when these are made regularly, and the records are studied by some competent person, can exact knowledge be obtained of the efficiency or otherwise of the firemen and furnaces. The waste gases contain carbon dioxide, moisture, nitrogen and unconsumed oxygen as regular constituents; and the percentages of carbon dioxide and oxygen respectively are the figures which enable one to say with what excess of air the combustion process is being maintained. If it were possible to obtain good combustion of bituminous coal with the theoretical amount of air, the exit gases would contain 19½ to 19 per cent. of CO_2 and no free oxygen, and 12 lbs. of dry air would be required to burn 1 lb. of coal. Since it is impossible to obtain good combustion of solid fuel with only the theoretical amount of air passing through the furnace, an excess of air is necessary, but the amount of this excess should not exceed 50 to 75 per cent. (corresponding to 12·6 and 10·9 per cent. of CO_2 respectively).

Tests showing percentages of CO_2 below the latter figure indicate that much more air is being passed through the furnaces than is required, and since all this air has to be raised to the combustion temperature (say 2,500° F.), and carries off some portion of heat to the chimney, it is evident that the smaller the excess the better.

A CO_2 test showing 10 to 13 per cent. is therefore the best for obtaining high efficiency from the boilers. Above 13 per cent. of CO_2 there is grave danger of allowing carbon monoxide and hydrocarbon gases to escape unconsumed with the exit gases, and it is unwise to attempt to reduce the excess of air below the 50 per cent. margin represented by 12·9 per cent. CO_2. Where attempts are being made, however, to reach a still higher efficiency, it is necessary to test the exit gases regularly for carbon monoxide and for methane, as well as for carbon dioxide and oxygen, and this demands a more complicated form of gas-testing apparatus.

A small form of the well-known Orsat gas-testing apparatus, which can be carried about the boiler plant, is shown in Fig. 52, and with the aid of this apparatus tests of the carbon dioxide and oxygen contents of the waste gases can be very quickly obtained.

The methods of use will be found described very fully in the handbook referred to below.[1]

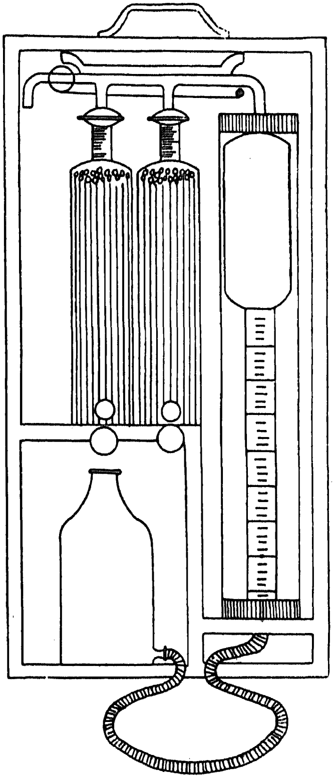


FIG. 52.—Portable form of Gas-testing Apparatus.

With the aid of the figures for the percentage of CO_2 and oxygen in the waste gases obtained by this apparatus, the presence or absence of carbon monoxide and other combustible gases can be ascertained by the following method of calculation.

---

[1] "Fuel Water and Gas Analysis for Steam Users." Constable & Co. 2nd Revised and Enlarged Edition, 1920.

Air contains 79 per cent. nitrogen and 20·8 per cent. oxygen, by volume. When burning a bituminous fuel of average quality, yielding 35 per cent. volatile matter on heating, about 1·8 per cent. of the oxygen of the air will be required to complete the combustion of the hydrogen contained in the coal, and therefore the air that remains will contain only 19 per cent. of free oxygen.

The tests for carbon dioxide and for oxygen when added together ought therefore to total 19 per cent. ; and if there is a continued deficiency in the tests when dealt with in this manner, it indicates that carbon monoxide or hydrocarbon gases are also present in the exit gases. When burning coke or anthracite fuels which contain only a small percentage of hydrogen and volatile hydrocarbons, this disappearance of oxygen does not occur. The CO_2 and oxygen tests of the waste gases, in such cases, when added together should equal the original oxygen content of the air, namely, 20·8 per cent.

In those power-plants where a large number of boilers are installed it will be found advisable to have one or two automatic CO_2 recorders in use, for it is useful to be able to obtain a *continuous record* of the CO_2 contents of the gases from any particular boiler that appears to be working badly, in addition to the tests of snap-samples of the gas obtained with the small Orsat apparatus.

AUTOMATIC RECORDERS.

It is now about fifteen years since automatic CO_2 recorders first made their appearance. For a time they enjoyed great popularity, and they were to be found in all boiler-houses where the engineers prided themselves upon being alive and up-to-date. The difficulties met with in keeping the apparatus in good working order, however, were considerable, and as they failed to satisfy the demands made upon them, they were discarded by many engineers who at first were most loud in their praise. Their failure was due not so much to defects in the apparatus, though no doubt some of them were unnecessarily complicated, as to defects in their installation and in their methods of use. In the first place, the pipe connections between the automatic gas-testing apparatus and the boiler flues were made too long and had too many joints, with the result that air-leakage occurred, and in some cases the pipes corroded up. Another common cause of failure, was the blocking of the filter used to remove the soot and moisture from the gases before they were tested ; but the most general cause was the placing of the apparatus in charge of an engineer or stoker who had had no previous training or experience in the care of delicate mechanism or glass apparatus.

To deal with these causes of trouble in order—the connecting pipe from the recorder to the individual boiler flues should never exceed 30 feet in length, and should be constructed, not of iron or lead, but of 6-feet lengths of glass-tubing, ½ inch in external diameter, joined together with couplings of the best red rubber, wired on. The joints will require attention, but if good rubber be used they will last six months or more, and they should be renewed at once when the rubber begins to crack. At each branch to a boiler or to the main flue a glass stopcock and T-piece must be inserted in the line, with the longer leg pointing vertically downwards. The tube that actually passes into the flue is attached to this leg, and must be of ⅜ inch external diameter hard potash glass, in order to withstand temperatures up to 800° C. without softening or melting. These dependent tubes, where they pass through the brickwork of the boiler setting, should be protected by flanged iron-guard tubes ¾ inch or 1 inch diameter, and should be fixed firmly in these with the aid of cork bungs. The glass stopcocks must be regularly cleaned and greased, and once a week the tightness of the whole system of connecting-tubes must be tested by closing all the stopcocks and working the water jet air-pump until a vacuum of 8 inches, as registered by a gauge connected to the line near the pump, is attained. Should this be impossible the leakage that destroys the vacuum must be sought for and stopped. At frequent intervals the dependent tubes that pass into the flues, and the main length of connecting tube, must be freed from internal soot and dust by the aid of low-pressure steam, or by flushing with *warm water*, the hard glass tubes being withdrawn from the flues and cooled before this treatment is carried out.

It is advisable to have a recorder installed for every six boilers, and to be able to connect this as desired to the flue from either the right or left-hand boiler fire (in the case of Lancashire boilers), and to the main flue behind each boiler. This gives a maximum of eighteen connections on any one line. The cabin or cupboard in which the apparatus is installed should be placed centrally, so that three of the boilers are on one side of it and three on the other. The tubes should be laid with a fall away from the central connection to the recorder, in order that the moisture which condenses in the line may be removed by opening the end stopcock of each branch.

The soot-filter may be constructed of sheet lead (although a glass one constructed on the laboratory desiccator principle would be better), and should be placed close to the recorder, so that there is only one on each connecting line, and this can then be kept under constant observation. It must be of the circular flat shallow type, which gives a large filtration area with a small cubical capacity, so that there is less "lag" in the test records. The joint between the two halves of the filter is made with a rubber gasket ring, and two external rings of hard lead or iron provided with bolts and thumbscrews. Glass-wool or asbestos-felt supported on wire gauze is used as the filtering medium; this must be removed and renewed daily or oftener, according to the amount of soot contained in the waste gases. The advantage of placing the filter close to the recorder is that only the gas actually tested is passed through it, whereas if it be placed upon the main connecting line all the gas withdrawn by the pump from the flues will pass through it, and it will require cleaning much more frequently.

When an ejector type of water pump is used to abstract the gas from the flues it is advisable to provide a separate water-supply tank fitted with a filtering attachment to retain fine particles of grit and other matter which might stop up the jet of the air-pump and cause it to stop working. A steady pressure or head of water is also required, in order to obtain satisfactory operation with this type of pump. This is most easily arranged for by installing a separate supply cistern with a floating ball-tap and lead run-off pipe.

Automatic recording apparatus falls into two broad classes, according as the percentage of carbon dioxide gas is measured by direct absorption in caustic potash, or some physical characteristic of the gas that is a criterion of the CO_2 contents is observed and measured.

It is not the author's purpose to describe the various types of CO_2 recorders in this chapter—and readers desirous of obtaining more information on this subject must refer to the larger handbook (see p. 159).

Enough has been said, however, to indicate the great importance of regular and systematic chemical examination of the waste gases in boiler plants, and to urge that the care of any automatic testing instruments installed should be placed in the hands of specially trained men, and not left to the charge of ordinary stokers or shift-engineers, who may happen to have a few spare minutes available, or may volunteer for the job. Many past failures with such instruments in the boiler-house are undoubtedly attributable to the neglect of this latter precaution; and some engineers have made the same mistake with these machines that they made at first with mechanical stokers, and have imagined that as they were automatic in action they did not require skilled attention. The lesson of experience, however, is that automatic apparatus of all kinds demands a well-trained and intelligent man to look after it and to keep it in order; and that the most certain way of asking for trouble in the boiler-house is to place insufficiently trained men in charge of mechanical stokers and carbon dioxide recording apparatus. When this lesson has been thoroughly learned by chief engineers the automatic types of recorder will once more come into favour, for with intelligent and skilled attention they can be of the greatest service in maintaining the conditions requisite for high efficiency in the combustion of low grade fuels under steam boilers.

1328

662·6 F01

DIAN INSTITUTE OF SCIENCE
LIBRARY
ORE. *

INDIAN INSTITUTE OF SCIENCE
LIBRARY
BANGALORE.

NAME INDEX

(pl. = place.)

ALTENHEIM and Wilson, 125

BABCOCK, 41
Babcock and Wilcox, 87, 136
Baly, 32
Barnsley, pl., 7
Beatty and Smith, 69
Bergen, pl., 22
Bettington, 77, 129, 170
Bismarck, pl., 42
Bitterfeld, pl., 39
Blaydon, pl., 129
Bolling, 121
Boncourt, 171
Booth and Kershaw, 180
Boys, 167
British Association, 2, 128
Broadbent, 103
Buenos Ayres Tramway Co., 69
Butow and Dobbelstein, 89, 90, 131

CADOGAN mine, 85
Caro. *See* Frank and Caro.
Cobb, 79
Cockerill Co., 130
Codigoro, pl., 33
Colorado, pl., 47, 49
Coxe, 87
Crossley, 29

DAKOTA. *See* North Dakota.
Davis, 44
Delaware Lackawanna and Western Railroad Co., 87
Del Rio (Texas), pl., 56
Denver, pl., 47
Dörr, 97, 103
Dürr, 90

EKENBERG, 24
"Elektron" Chemical Co., 39
Erhardt and Schmer, 91

FARNLEY Iron Co., 79
Fernald, 29, 55, 57, 74, 80
Frank and Caro, 32
Freeland, 52
Frey, 88
Frick & Co., 135
Froude. *See* Heenan and Froude.

GALAINE, 25
Gary, 136
Goodrich, 77
Grand Forks, pl., 50
Greiner, 130
Grieshein, pl., 39

HALLE, pl., 48
Hamilton, Robb & Co., 29
Hauto, pl., 81
Heenan and Froude, 97, 103
Herbertz, 97, 103
Heyl, 121
Hoover, 49
Horren, pl., 44
Horsfall, 97, 103
Huddersfield, pl., 108
Hughes Electric Co., 42
Humboldt, 98, 103
Humphreys, 56

INDIANA Steel Co., 135, 137
Institution of Electrical Engineers, 180

JEBSEN, 22
Jünker, 165

KERPELY, 6, 93
Kerr, 53
Kershaw. *See* Booth and Kershaw.
King, 79
Kohlman, 105
Kreisinger and Ray, 172, 182

LARSEN, 42

Lehigh Coal and Navigation Co., 81
Liege, pl., 130
Limbers, 23
London Hydraulic Power Co., 64
Louis, 7
Lyons & Co., 118

Manlove and Alliott, 103
Mann and Mustefeld, 92
Martin, 114
Maschinen Fabrik Augsburg, 92
Maxim, 88
Meldrum, 55, 102, 103
Messel, pl., 48
Mond, 32, 91, 92

Nanticoke Power Station, 87
New Destructor Co., 97
New Zealand, 52
Nicol, 65, 69, 116
Nicol and Scholfield, 62
North Dakota, 46

Orsat, 189
Ortmann, 135

Paisley, pl., 111
Philips, 120
Pintsch, 6
Pope, 141
Portadown, pl., 30
Portland, pl., 54
Pratt, 129, 125

Randall and Kreisinger, 43

Rauxel, 133
Rehmann, 6
Rockwell Manufacturing Co., 54
Ross and Scholfield, 116
Rotterdam, pl., 109
Rowlands Gill, pl., 129
Rust, 137

Schwelger Bog, pl., 33
Skabersjo, pl., 28
Sloan, 128
Society of Chemical Industry, 7, 32
Steuart, 37, 48

Tees, 6, 74
Terbeck, 131

Visby, pl., 29

Wallsend Slipway and Engineering Co., 118
Waste-Heat Electrical Generating Stations, Ltd., 127
Wefer, 131, 132, 133, 134
Wiesmoor Bog, pl., 15, 16
Willaston, pl., 44
Wilson. *See* Altenheim and Wilson.
Wilton, 72
Wright, 46

York Run, pl., 135

Ziegler, 22, 52
Zwingenberger, 52

ITE OF SCIENCE
RARY

SUBJECT INDEX

- Automatic CO_2 apparatus, 190

- Bagasse:
  - calorific and steam-raising value of, 52, 53
  - chemical and physical properties of, 52
  - methods of burning, 53
- Boilers. *See* Furnaces and boilers.
- British thermal units, definition of, 156
- Brown coal. *See* Lignite.

- Calorie, definition of, 156
- Calorimeter tests. *See* Laboratory tests of fuel.
- Coal left in mines, 2, 7, 9
- Coalite, 59
- Coke and coke-breeze:
  - ash in, 60
  - back-firing in coke-fired furnaces, 67
  - calorific and steam-raising value of, 59, 61, 66, 68, 69, 70, 71, 73, 74, 90
  - chemical and physical properties of, 59, 60, 65, 90
  - conditions of combustion, 61, 62, 64, 66, 67
  - dutch-oven type of furnace for burning, 66
  - forced draught for burning, 65, 66, 70, 72, 90
  - gasification of, 73, 74, 91, 92
  - German methods of firing with, 71, 72, 90, 92
  - grate forms required for burning, 61, 62
  - high temperatures in coke-fired furnaces, 67
  - moisture in, 60
  - radiated heat from, 71
  - rates of combustion of, 66
  - "Sandwich" feed for, 63, 64
  - typical tests of, 61

- Coke and coke-breeze—*continued.*
  - volatile matter in, 59, 90
  - Wilton apparatus for burning, 72
- Conservation of fuel, 2, 9
- Control of the combustion process:
  - automatic CO_2 recorders,
    - classification of, 193
    - difficulties of keeping in order, 190, 191
    - number of boilers to each apparatus, 192
    - pipe-connections, planning of, 191
    - skilled attention for, 193
    - soot filter, design of, 191, 192
    - suction pump for, 193
    - value of, 190
  - economisers:
    - purpose and advantages of, 186
    - improvements of, 186
  - excess of air, necessity of reducing, 185
  - heat losses, conditions for reduction of, 185, 186
  - waste gases,
    - carbon-dioxide as index of excess air, 188, 189
    - carbon-monoxide in, 189, 190
    - chemical composition, 188
    - fuel-equivalent of heat lost with, 187
    - heat carried away with, 185, 187
    - Orsat gas-testing apparatus, 189
    - oxygen in, 189
    - temperature of, 187, 188
    - temperature, measurements of, 187, 188
    - thermometers for taking temperature of, 187

Culm and washery-waste:
  Bettington boiler for burning, 77, 79, 80
  boilers and furnaces at Hauto, Pa., 82, 84
  chain-grate stokers for burning, 87, 88
  chemical and calorific tests of, 81, 88
  classification of, 82, 89, 90
  early types of furnace for combustion of, 77
  forced draught for, 89, 90, 93, 99
  gasification of, 91, 92, 93
  modern methods of treating dumps of, 81
  physical properties of, 82, 86, 89
  power derived from, 85, 86
  steam-raising value of, 79, 80, 88, 89, 90
  underfeed-stokers for, 86

DUMPS, growth of, at collieries, 76

FLAMELESS combustion, 171
Fuel conservation, 2, 9
Fuel sampling:
  bulk, rules for sampling coal in, 141
  cargoes, rules for sampling, 142
  conditions of fair sampling, 140, 145
  cost of sampling, 140
  crushing fuel samples, 142, 143
  hand-crushing of samples, 143
  Kenrick mill for grinding, 145, 146
  large deliveries, rules for sampling, 141
  lignite, preparing samples of, 147
  liquid fuels, methods of sampling, 147, 148
  marking fuel samples, 145
  mechanical crushers for samples, 143, 144
  mixing and grinding the final sample, 146
  peat, preparing samples of, 147
  pitch, methods of sampling, 148
  reducing samples to smaller bulk, 142, 143, 145

Fuel sampling—*continued.*
  relative size of sample and bulk delivery, 143
  skill needed for, 139, 140, 145, 150
  tar, methods of sampling, 148
  waggons, rules for sampling, 142
  wet samples, methods of treating, 145
  wood, preparing samples of, 147
Furnaces and boilers, choice and management of:
  air leakage, prevention of, 175, 179
  air pump, use of, for mixing gases, 177
  air regulating devices, 170, 173, 174, 175
  baffles for, 177
  balanced draught, 174
  Bettington boiler for dust-fuel, 77, 129, 170
  Boncourt system of heating by gas, 171
  chimney draught, cost of, 178
  circulation devices, 169, 172, 177
  closed ash pits, 175
  combustion chambers, purpose and size of, 174, 176, 177
  conditions required for good combustion, 173, 177
  depth of fuel bed, 176
  design and settling of boilers, 171
  draught-gauge, value of, 179
  draught-measurement, 179
  economisers, necessity of, 183
  fan-draught, 178, 179, 180, 183
  feed-water heaters, necessity of, 183
  flue-dust, mechanical removal of, 172
  forced-draught, 178, 179
  fuel-consumption per square foot of grate area, 176, 180
  gas-firing for boilers, 171
  hand-fired furnaces, 174, 175, 176
  heat-absorption by water in boiler, 181, 182, 184
  heat-insulation, 172, 173, 176
  heat-losses by waste gases, 173

Furnaces, &c.—*continued.*
  heat transfer in boilers, conditions of, 182, 183
  high efficiencies, conditions required for, 169, 173, 174, 175, 177, 182, 183, 184
  induced-draught, 178, 179
  Lancashire boilers, advantage and disadvantages of, 169, 170, 171, 176
  latent heat of water and steam, 182
  mechanical stokers, 170, 176, 177, 183
  natural chimney draught, defects of, 178
  preheated air supply, 169, 170, 175, 176
  radiation losses from boilers, 173
  requirements of a good boiler, 169, 174, 175, 180
  secondary air for combustion, regulation of, 170, 173, 174
  slag-wool for insulation, 173
  smoke prevention, 170, 173
  steaming capacities of boilers, increase of, 183
  steam jets for mixing gases, 177
  superheating, advantages of, 183
  waste gases, heat losses by, 173
  water-tube boilers, advantages and disadvantages of, 169, 170, 171, 177

GARBAGE. *See* Towns' refuse.
Gas producers for low-grade fuels:
  down-draught producers, 56
  eccentric grates for, 6
  Erhardt and Schmer type of, 91
  general characteristics of, 5, 91, 93
  high-pressure types of, 6
  Kerpely type of, 6, 73, 93
  Pintsch type of, 6
  Rehmann type of, 6
  Tees type of, 6, 74
  up-draught producers, 56
Gases, use of waste gases for steam generation, 124

LABORATORY tests of fuel:
  approximate analysis of, 148, 150, 155
Laboratory tests, &c.—*continued.*
  ash in, 148, 149, 150
  ash, determination of, 157
  back-pressure valve for bomb-calorimeter, 161
  bell type of calorimeter, 157, 159, 160, 162
  bomb type of calorimeter, 157, 160, 161, 162
  Boys' gas calorimeter, 167, 168
  briquette mould for calorimetric work, 157, 158
  British thermal unit, definition of, 156
  calorimeter, tests with, 149, 156
  calorie, definition of, 156
  cellulose blocks, for use with liquid fuels, 163, 164
  coke, determination of, 150, 152, 153, 154, 155
  composition of fuel, 148
  conversion data for B.Th.U., 165
  Darling's form of calorimeter, 159, 160
  elementary analysis of fuels, 148
  fixed carbon, determination of, 152, 153, 154
  gaseous fuels, calorimeter for, 164
  graphite, origin of in coke tests of fuel, 153, 154
  Junker's calorimeter for gases, 165, 166
  liquid fuels, calorific value of, 163
  Mahler-Donkin bomb-calorimeter, 160, 161, 162
  moisture in fuels, 148
  moisture, determination of, 149, 150
  oxygen for calorimetric work, 157
  platinum crucible for fuel tests, 152
  platinum dish, protection of, in calorimetric work, 161
  thermometers for calorimetric work, 156
  volatile matter in fuels, 150
  volatile matter, determination of, 152, 153, 154, 155
Lancashire boilers, 169, 170

- Lignite (brown coal):
  - air-dried lignite,
    - difficulties in burning, 41, 42
    - efficiency of, for steam-raising, 41, 42
    - furnaces and grates for, 39, 40, 41, 42, 43
  - area of deposits of, 37
  - briquetting,
    - cost of, at Horren, 46
    - developments of industry at Horren, 44
    - developments in U.S.A., 47
    - methods and machinery for, 44
    - tests of briquettes, 47, 50
  - chemical and physical properties of, 37, 41, 48
  - distillation,
    - ammonia, yields of, 47, 49
    - coke from, 49
    - composition of gas, 47, 50, 52
    - oil, yield of, 48, 49
    - retorts for, 49
  - gasification,
    - non-recovery of by-products, 51
    - small plants for, 52
    - tests made at Grand Forks, 50
    - yields of gas by, 52
- Low-grade fuels:
  - bagasse, 52
  - coke and coke-breeze, 6, 58
  - culm and pit refuse, 6, 76
  - definition of, 4, 89, 92
  - garbage, 95
  - gasification of, 5, 89, 92
  - lignite, 6, 37
  - methods of burning, 4, 89, 92
  - peat, 6, 11
  - pitch, 112
  - towns' refuse, 95
  - waste gases, 124
  - wood refuse, 54

- PEAT:
  - briquettes,
    - boiler furnaces and grates for, 18, 21
    - cost of steam-raising with, 19
    - dredgers for peat bogs, 16
    - dredgers, power required by, 29

- Peat—*continued.*
  - briquettes—*continued.*
    - machine-made briquettes, 14, 15, 16
    - power generation from, 15
    - pulping machines, 17
    - Wiesmoor bog and power station, 15, 16
  - carbonising,
    - dry carbonising by Jebsen process, 22
    - dry carbonising by Ziegler process, 22, 23
    - general principles of, 21
    - wet carbonising, 22, 24
    - wet carbonising by Ekenberg process, 24
    - wet carbonising by Galaine process, 25
  - future developments, lines of, 35, 36
  - gasifying,
    - ammonia, recovery by, 32, 33, 34
    - composition of gas, 27, 30, 33
    - cost of power by, 28, 31, 33
    - double combustion zone producers, 26
    - plant at Skabersjo, 28
    - plant at Visby, 29
    - tar, difficulties caused by, 31
    - tests of peat in gas producers, 26, 27
  - natural deposits and characteristics,
    - analyses, 13
    - area and extent of peat bogs, 11
    - calorific value of, 14, 18
    - chemical changes during formation, 13
    - composition and constitution, 12
    - hydrogen, 21
    - origin of moisture, 13
    - volatile matter, 13
  - powdered peat,
    - cost of preparing, 34
    - efficiency of, 35
- Pitch:
  - calorific value of, 113, 114, 115
  - chemical and physical properties of, 113, 114, 115

Pitch—*continued.*
  combustion, difficulties of, 115, 120
  conditions required for combustion of, 116
  creosote, use of mixtures of pitch and, 118, 121, 122
  exports of, before the War, 113
  fall in price of, 112
  future progress in utilisation of, 122
  Nicol's type of fire-bar for burning, 116, 117
  production of, in tar-distillation plants, 112, 114, 120
  transport of, 120
  use of, as a liquid fuel, 118, 120, 121
  use of, for internal combustion engines, 121
  use of, under steam boilers, 117, 118

RESERVES of coal, 3

SAMPLING fuel. *See* Fuel sampling.
Saw-mill refuse. *See* Wood refuse.
Shale and slate in coal, 81, 144, 145

TOWNS' refuse:
  ash and slag from combustion of, 99
  average evaporative efficiency of, 99
  calorific value of, 96, 98, 99, 107
  capacity of various types of destructor, 104
  clinker, from improved methods of disposal, 102, 105, 106
  collection and storage of, 103, 109
  combined electricity and destructor plants, 107
  composition of London refuse, 99
  dust settling chamber for destructor plants, 102, 109
  early form of destructor, 95
  efficiency of various types of destructor for, 97, 98, 105, 110

Towns' refuse—*continued.*
  fans, use of, for burning, 100, 104, 106
  forced draught for burning, 95, 100, 106
  German types of destructor, 97, 98, 103, 104
  grate areas of various types of destructor, 104, 109
  Heenan and Froude destructor, 97, 103, 109
  hollow walls for destructor cells, 97, 104
  Horsfall destructor, 97, 103
  improvements in destructor design and control, 99, 100, 102, 103, 104, 105, 107
  Manlove and Alliott destructor, 103, 109
  Meldrum destructor, 103
  preheated air supply for burning, 95, 97, 100, 103, 105
  revenue from destructor plants, 109, 110, 111
  shaft type of destructor, 104, 105, 106
  steam-raising value of, 96, 97, 98, 107
  temperature attained in destructors, 104, 106
  trough grates for clinker, 102
  variations in fuel value of, 96, 98
  water-cooled hearth for destructors, 104

WASTE gases:
  air supply to burners, 125, 133
  back-firing, dangers and prevention of, 125, 131, 134
  blast furnaces, 124, 127
  boiler efficiencies, 126, 127, 130, 135
  boilers for gas firing, 125, 129, 135, 136, 137
  burners for, 124, 125, 131
  carbon-monoxide in, 124, 127, 133
  cement-kiln gases, 127
  coke-oven gases, 124, 127, 129
  composition of, 127, 133
  copper-refining furnace gases, 127
  cost of steam raising by, 133
  electric power form, 128
  excess air in burning, 133

Waste gases—*continued.*
  fan draught, 126, 136
  gas engines, 130
  gasometer, use of, for storage, 135
  heat-transfer in boilers, 130, 136, 137, 138
  hydrogen in, 124, 127, 133
  improved methods of burning, 132, 133
  metallurgical furnace gases, 124, 126, 136, 137, 138
  natural draught, 126, 130
  open-hearth furnaces, 127, 137
  potential heat of, 124
  sensible heat of, 124, 127
  steam-raising value of, 126, 129, 132, 133, 135
  steel reheating furnace gases, 124, 126, 127
Waste gases—*continued.*
  temperature, reduction of, 126, 130, 136, 137, 138
  thermal value of, 126, 127, 130
  waste heat boilers, 126, 136
Wasted coal, 2, 7, 9
Water-tube boilers, 169, 170
Wood and wood refuse:
  calorific and steam-raising value of, 54, 55
  Dutch-oven type of furnace for, 54
  gasification of, 55, 56
  Meldrums' furnace for, 55
  power obtained from different kinds of, 56, 57
  tar from, 56
  weight of 1 cubic foot of, 54

WHITEFRIARS PRESS, LTD., LONDON AND TONBRIDGE.

THE USE OF LOW-GRADE AND WASTE FUELS FOR POWER GENERATION

BY

JOHN B. C. KERSHAW, F.I.C.

AUTHOR OF "SMOKE PREVENTION," ETC.

LONDON
CONSTABLE & COMPANY LTD
10 ORANGE STREET WC